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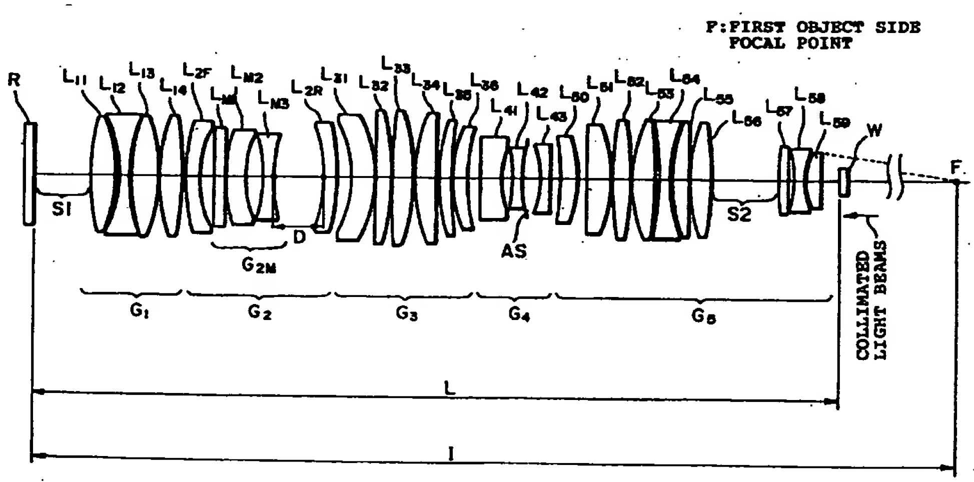
(54) Exposure apparatus

(57) The present invention relates to an exposure apparatus having a high-performance projection optical system having a relatively large numerical aperture and achieving bitelecentricity and superior correction of aberrations, particularly distortion, in a very wide exposure area. Particularly, the projection optical system according to the present invention is composed of a first lens group G_1 with a positive refracting power, a second lens group G_2 with a negative refracting power, a third lens group G_3 with a positive refracting power, a fourth lens group G_4 with a negative refracting power, and a fifth lens group G_5 with a positive refracting power in order from the side of a first object R. The present invention is directed to finding suitable ranges of focal lengths for the first to fifth lens groups G_1-G_5, based on the above arrangement.

Fig. 1



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Description

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to an exposure apparatus having a projection optical system for projecting a pattern of a first object onto a photosensitive substrate etc. as a second object, and more particularly to a projection optical system suitably applicable to projection exposure of a pattern for semiconductor or liquid crystal formed on a reticle (mask) as the first object onto the substrate (semiconductor wafer, plate, etc.) as the second object.

Related background art

As the patterns of integrated circuits become finer and finer, the resolving power required for the exposure apparatus used in printing of wafer also becomes higher and higher. In addition to the improvement in resolving power, the projection optical systems of the exposure apparatus are required to decrease image stress.

Here, the image stress includes those due to bowing etc. of the printed wafer on the image side of projection optical system and those due to bowing etc. of the reticle with circuit pattern etc. written therein, on the object side of projection optical system, as well as distortion caused by the projection optical system.

With a recent further progress of fineness tendency of transfer patterns, demands to decrease the image stress are also becoming harder.

Then, in order to decrease effects of the wafer bowing on the image stress, the conventional technology has employed the so-called image-side telecentric optical system that located the exit pupil position at a farther point on the image side of projection optical system.

On the other hand, the image stress due to the bowing of reticle can also be reduced by employing a so-called object-side telecentric optical system that locates the entrance pupil position of projection optical system at a farther point from the object plane, and there are suggestions to locate the entrance pupil position of projection optical system at a relatively far position from the object plane as described. Examples of those suggestions are described for example in Japanese Laid-open Patent Applications No. 63-118115 and No. 5-173065 and U.S Patent No.5,260,832.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a high-performance projection optical system having a relatively large numerical aperture and achieving the bitelecentricity and good correction of aberrations, particularly distortion, in a very wide exposure area (exposure field). In general, the projection optical system can be applied to an exposure apparatus.

To obtain the remarkably wider exposure area than conventional projection optical systems, the present invention involves an exposure apparatus having a high-performance projection optical system comprising at least a first stage (wafer stage) allowing a photosensitive substrate (for example, a semiconductor wafer coated with a photosensitive material such as a photoresist) to be held on a main surface thereof, an illumination optical system having a light source for emitting exposure light of a predetermined wavelength and transferring a predetermined pattern on a mask onto the substrate, and a projecting optical system for projecting an image on the mask, on the substrate surface. And the exposure apparatus further comprises a second stage (reticle stage) for supporting the mask at a predetermined position. The above projecting optical system is provided between the first stage and the second stage and projects an image of a first object (for example, a mask with a pattern such as an integrated circuit) onto a second object (for example, a photosensitive substrate).

As shown in Fig. 1, the projection optical system comprises a first lens group G_1 with positive refracting power, a second lens group G_2 with negative refracting power, a third lens group G_3 with positive refracting power, a fourth lens group G_4 with negative refracting power, and a fifth lens group G_5 with positive refracting power in the named order from the side of the first object R. A magnification of the projection optical system is 1/2.5 so as to obtain a wider exposure field.

The first lens group G_1 with the positive refracting power contributes to correction of distortion while maintaining the telecentricity. Specifically, the first lens group G_1 generates positive distortion to correct in a good balance for negative distortion generated by a plurality of lens groups located on the second object side of the first lens group G_1. The second lens group G_2 with the negative refracting power and the fourth lens group G_4 with the negative refracting power contribute mainly to correction of Petzval sum to flatten the image surface. The second lens group G_2 with the negative refracting power and the third lens group G_3 with the positive refracting power compose an inverted telephoto system in combination and contribute to securing the back focus (a distance from an optical surface such as a lens surface closest to the second object W in the projection optical system to the second object W) of the projection optical system. The

fifth lens group G_5 with the positive refracting power contributes mainly to suppressing appearance of distortion, and suppressing appearance of spherical aberration in particular as much as possible in order to fully meet a demand to achieve a high numerical aperture on the second object side.

Further, when f_1 is a focal length of the first lens group G_1, f_2 is a focal length of the second lens group G_2, f_3 is a focal length of the third lens group G_3, f_4 is a focal length of the fourth lens group G_4, f_5 is a focal length of the fifth lens group G_5, f_{1-3} is a composite focal length of the first lens group G_1 to third lens group G_3, f_{4-5} is a composite focal length of the fourth lens group G_4 and the fifth lens group G_5, and L is a distance from the first object R to the second object W, the following conditions are satisfied:

$$0.1 < f_1/f_3 < 17 \tag{1}$$

$$0.1 < f_2/f_4 < 14 \tag{2}$$

$$0.01 < f_5/L < 0.8 \tag{3}$$

$$f_{1-3}/f_{4-5} < 2.5. \tag{4}$$

The condition (1) defines an optimum ratio between the focal length f_1 of the first lens group G_1 with positive refracting power and the focal length f_3 of the third lens group G_3 with positive refracting power, which is an optimum refracting power (power) balance between the first lens group G_1 and the third lens group G_3. This condition (1) is mainly for correcting the distortion in a good balance. Below the lower limit of this condition (1) a large negative distortion is produced because the refracting power of the third lens group G_3 becomes relatively weak to the refracting power of the first lens group G_1. Above the upper limit of the condition (1) a large negative distortion is produced because the refracting power of the first lens group G_1 becomes relatively weak to the refracting power of the third lens group G_3.

The condition (2) defines an optimum ratio between the focal length f_2 of the second lens group G_2 with negative refracting power and the focal length f_4 of the fourth lens group G_4 with negative refracting power, which is an optimum refracting power (power) balance between the second lens group G_2 and the fourth lens group G_4. This condition (2) is mainly for keeping the Petzval sum small so as to correct the curvature of field well while securing a wide exposure field. Below the lower limit of the condition (2), a large positive Petzval sum appears because the refracting power of the fourth lens group G_4 becomes relatively weak to the refracting power of the second lens group G_2. Above the upper limit of the condition (2) a large positive Petzval sum appears because the refracting power of the second lens group G_2 becomes relatively weak to the refracting power of the fourth lens group G_4. In order to correct the Petzval sum in a better balance under a wide exposure field by making the refracting power of the fourth lens group G_4 strong relative to the refracting power of the second lens group G_2, the lower limit of the above condition (2) is preferably set to 0.8, i.e., $0.8 < f_2/f_4$.

The condition (3) defines an optimum ratio between the focal length f_5 of the fifth lens group G_5 with positive refracting power and the distance (object-image distance) L from the first object R (reticle etc.) and the second object W (wafer etc.). This condition (3) is for correcting the spherical aberration, distortion, and Petzval sum in a good balance while keeping a large numerical aperture. Below the lower limit of this condition (3) the refracting power of the fifth lens group G_5 is too strong, so that this fifth lens group G_5 generates not only a negative distortion but also a great negative spherical aberration. Above the upper limit of this condition (3) the refracting power of the fifth lens group G_5 is too weak, so that the refracting power of the fourth lens group G_4 with negative refracting power inevitably also becomes weak therewith, thereby resulting in failing to correct the Petzval sum well.

The condition (4) defines an optimum ratio of the composite focal length f_{1-3} of the first positive lens group G_1, the second negative lens group G_2, and the third positive lens G_3 to the composite focal length f_{4-5} of the fourth negative lens group G_4 and the fifth positive lens group G_5 to achieve a sufficiently wide exposure area and to effect sufficient correction for distortion. Above the upper limit of this condition (4), it becomes difficult to secure a sufficiently wide exposure area and negative distortion will appear. In order to suppress appearance of positive distortion, the lower limit of the above condition (4) is preferably set to 1.5, as $1.5 < f_{1-3}/f_{4-5}$. For better correction for negative distortion, the upper limit of the above condition (4) is preferably set to 2.2, as $f_{1-3}/f_{4-5} < 2.2$.

On the basis of the above composition it is preferred that when I is an axial distance from the first object R to the first-object-side focal point F of the entire projection optical system and L is the distance from the first object R to the second object W, the following condition be satisfied:

$$1.0 < I/L \tag{5}$$

The condition (5) defines an optimum ratio between the axial distance I from the first object R to the first-object-side focal point F of the entire projection optical system and the distance (object-image distance) L from the first object R (reticle etc.) to the second object W (wafer etc.). Here, the first-object-side focal point F of the entire projection optical

system means an intersecting point of outgoing light from the projection optical system with the optical axis after collimated light beams are let to enter the projection optical system on the second object side in the paraxial region with respect to the optical axis of the projection optical system and when the light beams in the paraxial region are outgoing from the projection optical system. Below the lower limit of this condition (5) the first-object-side telecentricity of the projection optical system will become considerably destroyed, so that changes of magnification and distortion due to an axial deviation of the first object R will become large. As a result, it becomes difficult to faithfully project an image of the first object R at a desired magnification onto the second object W. In order to fully suppress the changes of magnification and distortion due to the axial deviation of the first object R, the lower limit of the above condition (5) is preferably set to 1.7, i.e., $1.7 < I/L$. Further, in order to correct a spherical aberration and a distortion of the pupil both in a good balance while maintaining the compact design of the projection optical system, the upper limit of the above condition (5) is preferably set to 6.8, i.e., $I/L < 6.8$.

In the present invention it is also preferred that the second lens group G_2 comprise a front lens L_{2F} with a negative refracting power disposed as closest to the first object R and shaped with a concave surface to the second object W, a rear lens L_{2R} of a meniscus shape with a negative refracting power disposed as closest to the second object W and shaped with a concave surface to the first object R, and an intermediate lens group G_{2M} disposed between the front lens L_{2F} in the second lens group G_2 and the rear lens L_{2R} in the second lens group G_2, and that the intermediate lens group G_{2M} comprise at least a first lens L_{M1} with a positive refracting power, a second lens L_{M2} with a negative refracting power, and a third lens L_{M3} with a negative refracting power in order from the side of the first object R.

Here, in the second lens group G_2, the front lens L_{2F} with the negative refracting power disposed as closest to the first object R and shaped with the concave surface to the second object W contributes to correction for curvature of field and coma, and the rear lens L_{2R} of the meniscus shape with the negative refracting power disposed as closest to the second object W in the second lens group G_2 and shaped with the concave surface to the first object R contributes mainly to correction for coma. The rear lens L_{2R} also contributes to correction for curvature of field. In the intermediate lens group G_{2M} disposed between the front lens L_{2F} and the rear lens L_{2R}, the first lens L_{M1} with the positive refracting power contributes to correction for negative distortion generated by the second and third lenses L_{M2}, L_{M3} with the negative refracting powers greatly contributing to correction for curvature of field. In the intermediate lens G_{2M} appearance of coma can be suppressed because there are two or more lenses of negative refracting powers placed on the second object side of the first lens L_{M1} with the positive refracting power.

Further, it is preferred that when f_n is a composite focal length of from the second lens to the third lens in the second lens group G_2 and L is the distance from the first object R to the second object W, the following condition be satisfied:

$$-1.4 < f_n/L < -0.123. \qquad (6)$$

The condition (6) defines an appropriate ratio of the composite focal length f_n of from the second lens L_{M2} with the negative refracting power to the third lens L_{M3} with the negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2 to the distance (object-to-image distance) L from the first object R to the second object W. The composite focal length f_n of from the second lens L_{M2} with the negative refracting power to the third lens L_{M3} with the negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2, stated herein, does not mean only the composite focal length of the two lenses, the second lens L_{M2} and the third lens L_{M3}, but also means a composite focal length of two or more lenses of from the second lens L_{M2} to the third lens L_{M3} in the cases where a plurality of lenses are present between the second lens L_{M2} and the third lens L_{M3}.

This condition (6) is for keeping the Petzval sum small as suppressing appearance of negative distortion. Below the lower limit of this condition (6), the refracting power becomes too weak of the negative sub-lens group including at least two negative lenses of from the second negative lens L_{M2} to the third negative lens L_{M3} in the intermediate lens group G_{2M} in the second lens group G_2, which will result in giving rise to large positive Petzval sum and weakening the refracting power of the third lens group G_3, thus making it difficult to design the projection optical system in compact structure. For sufficiently compact design with good correction for Petzval sum, the lower limit of the above condition (6) is preferably set to -0.150, as $-0.150 < f_n/L$.

Above the upper limit of this condition (6), the composite refracting power becomes too strong of the sub-lens group including at least two negative lenses of from the second negative lens L_{M2} to the third negative lens L_{M3} in the intermediate lens group G_{2M} in the second lens group G_2, which makes it difficult to well correct negative distortion across a wide exposure area. For sufficient correction for distortion and coma, the upper limit of the above condition (6) is preferably set to -0.129, as $f_n/L < -0.129$.

For good correction mainly for third-order spherical aberration, the fifth lens group G_5 preferably comprises a negative lens L_{54} of a biconcave shape, a first positive lens L_{53} disposed as adjacent to the negative lens L_{54} of the biconcave shape on the first object side and shaped with a convex surface to the second object W, and a second positive lens L_{55} disposed as adjacent to the negative lens of the biconcave shape on the second object side and shaped with a convex surface to the first object R.

Further, it is also preferred that when r_{5p1} is a radius of curvature of the convex surface of the first positive lens L_{53} in the fifth lens group G_5 and r_{5n1} is a radius of curvature of a concave surface on the first object side, of the negative lens L_{54} of the biconcave shape in the fifth lens group G_5, the following condition be satisfied:

$$0 < (r_{5p1} - r_{5n1})/(r_{5p1} + r_{5n1}) < 1. \qquad (7)$$

It is also preferred that when r_{5n2} is a radius of curvature of a concave surface on the second object side, of the negative lens L_{54} of the biconcave shape in the fifth lens group G_5 and r_{5p2} is a radius of curvature of the convex surface of the second positive lens L_{55} in the fifth lens group G_5, the following condition be satisfied:

$$0 < (r_{5p2} - r_{5n2})/(r_{5p2} + r_{5n2}) < 1. \qquad (8)$$

The condition (7) and condition (8) define appropriate shapes of gas lenses formed on the both sides of the negative lens L_{54} of the biconcave shape in the fifth lens group G_5 so as to effect good correction for third-order spherical aberration. Here, below the lower limit of condition (7) or condition (8), correction for third-order spherical aberration becomes insufficient; in contrast, above the upper limit of condition (7) or condition (8), the third-order spherical aberration becomes overcorrected, resulting in unpreferable correction in either case.

Here, for better correction for the third-order spherical aberration, the lower limit of the condition (7) is more preferably set to 0.01, as $0.01 < (r_{5p1} - r_{5n1})/(r_{5p1} + r_{5n1})$, and the upper limit of condition (7) is more preferably set to 0.7, as $(r_{5p1} - r_{5n1})/(r_{5p1} + r_{5n1}) < 0.7$. For better correction for the third-order spherical aberration, the lower limit of the condition (8) is more preferably set to 0.01, as $0.01 < (r_{5p2} - r_{5n2})/(r_{5p2} + r_{5n2})$, and the upper limit of the condition (8) is more preferably set to 0.7, as $(r_{5p2} - r_{5n2})/(r_{5p2} + r_{5n2}) < 0.7$. Further better correction for the third-order spherical aberration can be expected when the above condition (7) and condition (8) both are satisfied.

Here, it is preferred that the negative lens L_{54} of the biconcave shape, the first positive lens L_{53} disposed as adjacent on the first object side to the negative lens L_{54} of the biconcave shape and shaped with the convex surface to the second object W, and the second positive lens L_{55} disposed as adjacent on the second object side to the negative lens L_{54} of the biconcave shape and shaped with the convex surface to the first object R be disposed between at least one positive lens, for example lens L_{52}, in the fifth lens group G_5 and at least one positive lens, for example lens L_{56}, in the fifth lens G_5. This constitution can suppress appearance of higher-order spherical aberration, which tends to appear as the numerical aperture increases. As a result, a concave lens will not be necessary at a space S2 between the lens L_{56} and the lens L_{57}.

It is also preferred that when f_3 is the focal length of the third lens group G_3 and f_5 is the focal length of the fifth lens group G_5, the following condition be satisfied:

$$0.80 < f_3/f_5 < 1.00. \qquad (9)$$

The above condition (9) defines a preferred ratio of refracting powers of the third lens group G_3 and the fifth lens group G_5. First, an arrangement of nearly equal refracting powers of the third lens group G_3 and the fifth lens group G_5 can suppress appearance of asymmetric aberration (particularly, coma and distortion); and the arrangement that the refracting power of the fifth lens group G_5 is slightly weaker than that of the third lens group G_3, as in the condition (9), can suppress appearance of negative distortion in particular.

Here, below the lower limit of condition (9), positive distortion and coma will appear, which is not preferred. Above the upper limit of condition (9), negative distortion and coma will appear, which is not preferred.

It is also preferred that the fourth lens group G_4 comprise a front lens L_{41} with a negative refracting power disposed as closest to the first object R and shaped with a concave surface to the second object W, a rear lens L_{43} with a negative refracting power disposed as closest to the second object W and shaped with a concave surface to the first object R, and at least one negative lens L_{42} disposed between the front lens L_{41} in the fourth lens group G_4 and the rear lens L_{43} in the fourth lens group G_4. Here, the Petzval sum and spherical aberration can be well corrected by the arrangement in which one or more negative lenses are disposed between the front lens L_{41} and the rear lens L_{43} in the fourth lens group G_4. Further, it is further preferred that when r_{4F} is a radius of curvature of a second-object-side surface of the front lens L_{41} disposed as closest to the first object R in the fourth lens group G_4 and r_{4R1} a radius of curvature of a first-object-side surface of the rear lens L_{43} disposed as closest to the second object W in the fourth lens G_4, the following condition be satisfied:

$$1.03 < |(r_{4F} - r_{4R1})/(r_{4F} + r_{4R1})|. \qquad (10)$$

Below the lower limit of condition (10), coma will appear, thus not preferred. Further, in order to suppress appearance of coma, the lower limit of condition (10) is preferably set to 1.10, as $1.10 < |(r_{4F} - r_{4R1})/(r_{4F} + r_{4R1})|$.

It is also preferred that when D is an axial distance from a second-object-side lens surface of the third lens L_{M3} with the negative refracting power in the intermediate lens group G_{2M} in the second lens group G_2 to a first-object-side lens surface of the rear lens L_{2R} in the second lens group G_2 and L is the distance from the first object R to the second object W, the following condition be satisfied:

$$0.05 < D/L < 0.4. \qquad (11)$$

Below the lower limit of condition (11), it becomes difficult to secure a sufficient back focus on the second object side and to well correct for the Petzval sum. Above the upper limit of condition (11), large coma and negative distortion will appear. Further, for example, in order to avoid mechanical interference between a reticle stage for holding a reticle R as a first object and the first lens group G_1, there are cases that a sufficient space S1 is desired to be secured between the first object R and the first lens group G_1, but above the upper limit of condition (11), there is a problem that it becomes difficult to secure the sufficient space S1.

It is also preferred that when f_4 is the focal length of the fourth lens group G_4 and L is the distance from the first object R to the second object W, the following condition be satisfied:

$$-0.098 < f_4/L < -0.005. \qquad (12)$$

Below the lower limit of condition (12), correction for spherical aberration becomes difficult, thus not preferred. Also, above the upper limit of condition (12), coma will appear, thus not preferred. For good correction for spherical aberration and Petzval sum, the lower limit of condition (12) is preferably set to -0.078, as $-0.078 < f_4/L$, and for suppressing appearance of coma, the upper limit of condition (12) is preferably set to -0.047, as $f_4/L < -0.047$.

It is also preferred that when f_2 is the focal length of the second lens group G_2 and L is the distance from the first object R to the second object W, the following condition be satisfied:

$$-0.8 < f_2/L < -0.050. \qquad (13)$$

Here, below the lower limit of condition (13), positive Petzval sum will appear, thus not preferred. Also, above the upper limit of condition (13), negative distortion will appear, thus not preferred. For better correction for Petzval sum, the lower limit of condition (13) is preferably set to -0.16, as $-0.16 < f_2/L$.

It is also preferred that the fourth lens group G_4 comprise a front lens L_{41} with a negative refracting power disposed as closest to the first object R and shaped with a concave surface to the second object W, a rear lens L_{43} with a negative refracting power disposed as closest to the second object W and shaped with a concave surface to the first object R, and at least one negative lens L_{42} disposed between the front lens L_{41} in the fourth lens group G_4 and the rear lens L_{43} in the fourth lens group G_4, and that when r_{4R1} is a radius of curvature of a first-object-side surface of the rear lens L_{43} disposed as closest to the second object W in the fourth lens group G_4 and r_{4R2} is a radius of curvature of a second-object-side surface of the rear lens L_{43}, the following condition be satisfied:

$$-1.00 \leqq (r_{4R1} - r_{4R2})/(r_{4R1} + r_{4R2}) < 0. \qquad (14)$$

Below the lower limit of condition (14), the negative, rear lens L_{43} located as closest to the second object W in the fourth lens group G_4 becomes of a biconcave shape to generate higher-order spherical aberration; in contrast, above the upper limit of condition (14), the negative, rear lens L_{43} located as closest to the second object W in the fourth lens group G_4 will have a positive refracting power, so that correction of Petzval sum tends to become difficult.

It is also preferred that the first lens L_{M1} with the positive refracting power in the intermediate lens group G_{2M} in the second lens group G_2 have a lens shape with a convex surface to the second object W and that when Φ_{21} is a refracting power of the second-object-side lens surface of the first lens L_{M1} with the positive refracting power in the intermediate lens group G_{2M} in the second lens group G_2 and L is the distance from the first object R to the second object W, the following condition be satisfied:

$$0.54 < 1/(\Phi_{21} \cdot L) < 10. \qquad (15)$$

The refracting power of the second-object-side lens surface, stated herein, of the first lens L_{M1} with positive refracting power in the intermediate lens group G_{2M} is given by the following formula when a refractive index of a medium for the first lens L_{M1} is n_1, a refracting index of a medium in contact with the second-object-side lens surface of the first lens L_{M1} is n_2, and a radius of curvature of the second-object-side lens surface of the first lens L_{M1} is r_{21}.

$$\Phi_{21} = (n_2 - n_1)/r_{21}$$

Below the lower limit of condition (15), higher-order distortion will appear; in contrast, above the upper limit of condition (15), the first lens group G_1 needs to more overcorrect distortion, which will generate spherical aberration of pupil, thus not preferred.

It is also preferred that when f_{2F} is a focal length of the front lens L_{2F} with the negative refracting power disposed as closest to the first object R in the second lens group G_2 and shaped with the concave surface to the second object W and f_{2R} is a focal length of the rear lens L_{2R} with the negative refracting power disposed as closest to the second object W in the second lens group G_2 and shaped with the concave surface to the first object R, the following condition be satisfied:

$$0 \leq f_{2F}/f_{2R} < 18. \qquad (16)$$

The condition (16) defines an optimum ratio between the focal length f_{2R} of the rear lens L_{2RF} in the second lens group G_2 and the focal length f_{2F} of the front lens L_{2F} in the second lens group G_2. Below the lower limit and above the upper limit of this condition (16), the balance of the refracting power of the first lens group G_1 or the third lens group G_3 is destroyed, it becomes difficult to well correct distortion or to simultaneously well correct Petzval sum and astigmatism.

For better correction for Petzval sum, the intermediate lens group G_{2M} in the second lens group G_2 preferably has a negative refracting power.

Also, for good correction for Petzval sum, it is preferred that only the second lens L_{M2} and the third lens L_{M3} have negative refracting powers in the intermediate lens group G_{2M}. It is preferred that when f_{22} is the focal length of the second lens L_{M2} with the negative refracting power in the second lens group G_2 and f_{23} the focal length of the third lens L_{M3} with the negative refracting power in the second lens group G_2, the following condition (17) be satisfied:

$$0.7 < f_{22}/f_{23}. \qquad (17)$$

Below the lower limit of condition (17), the refracting power of the second negative lens L_{M2} becomes relatively stronger than the refracting power of the third negative lens L_{M3}, and the second negative lens L_{M2} generates large coma and negative distortion. For good correction for Petzval sum, the lower limit of the above condition (17) is preferably set to 1.6, as $1.6 < f_{22}/f_{23}$. For suppressing appearance of coma and negative distortion, the upper limit of the above condition (17) is preferably set to 18, as $f_{22}/f_{23} < 18$.

For the above lens groups G_1-G_5 to achieve satisfactory aberration correction functions, specifically, they are desired to be constructed in the following arrangements.

First, for the first lens group G_1 to have a function to suppress appearance of higher-order distortion and appearance of spherical aberration of pupil, the first lens group G_1 preferably has at least two positive lenses; for the second lens group G_2 to suppress appearance of coma while correcting Petzval sum, the second lens group G_2 preferably has at least two negative lenses. For the third lens group G_3 to have a function to suppress degradation of spherical aberration and Petzval sum, the third lens group G_3 preferably has at least three positive lenses; further, for the fourth lens group G_4 to have a function to suppress appearance of coma as correcting Petzval sum, the fourth lens group G_4 preferably has at least three negative lenses. For the fifth lens group G_5 to have a function to suppress appearance of negative distortion and spherical aberration, the fifth lens group G_5 preferably has at least five positive lenses. Further, for the fifth lens group G_5 to have a function to correct spherical aberration, the fifth lens group G_5 preferably has at least one negative lens.

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not to be considered as limiting the present invention.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art form this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is drawing to show parameters defined in embodiments of the present invention.

Fig. 2 is a drawing to show schematic structure of an exposure apparatus to which the projection optical system according to the present invention is applied.

Fig. 3 is a lens arrangement drawing of the projection optical system in the first embodiment according to the present invention.

Fig. 4 is a lens arrangement drawing of the projection optical system in the second embodiment according to the present invention.

Fig. 5 is a lens arrangement drawing of the projection optical system in the third embodiment according to the present invention.

Fig. 6 is a lens arrangement drawing of the projection optical system in the fourth embodiment according to the present invention.

Fig. 7 is aberration diagrams to show aberrations in the projection optical system of the first embodiment as shown in Fig. 3.

Fig. 8 is aberration diagrams to show aberrations in the projection optical system of the second embodiment as shown in Fig. 4.

Fig. 9 is aberration diagrams to show aberrations in the projection optical system of the third embodiment as shown in Fig. 5.

Fig. 10 is aberration diagrams to show aberrations in the projection optical system of the fourth embodiment as shown in Fig. 6.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Various embodiments of the projection optical system according to the present invention will be described with reference to the drawings. In the examples, the present invention is applied to the projection optical system in the projection exposure apparatus for projecting an image of patterns of reticle onto a wafer coated with a photoresist. Fig. 2 shows a basic structure of the exposure apparatus according to the present invention. As shown in Fig. 2, an exposure apparatus of the present invention comprises at least a wafer stage 3 allowing a photosensitive substrate W to be held on a main surface 3a thereof, an illumination optical system 1 for emitting exposure light of a predetermined wavelength and transferring a predetermined pattern of a mask (reticle R) onto the substrate W, a light source 100 for supplying an exposure light to the illumination optical system 1, a projection optical system 5 provided between a first surface P1 (object plane) on which the mask R is disposed and a second surface P2 (image plane) to which a surface of the substrate W is corresponded, for projecting an image of the pattern of the mask R onto the substrate W. The illumination optical system 1 includes an alignment optical system 110 for adjusting a relative positions between the mask R and the wafer W, and the mask R is disposed on a reticle stage 2 which is movable in parallel with respect to the main surface of the wafer stage 3. A reticle exchange system 200 conveys and changes a reticle (mask R) to be set on the reticle stage 2. The reticle exchange system 200 includes a stage driver for moving the reticle stage 2 in parallel with respect to the main surface 3a of the wafer stage 3. The projection optical system 5 has a space permitting an aperture stop 6 (AS) to be set therein. The sensitive substrate W comprises a wafer 8 such as a silicon wafer or a glass plate, etc., and a photosensitive material 7 such as a photoresist or the like coating a surface of the wafer 8. The wafer stage 3 is moved in parallel with respect to a object plane P1 by a stage control system 300. Further, since a main control section 400 such as a computer system controls the light source 100, the reticle exchange system 200, the stage control system 300 or the like, the exposure apparatus can perform a harmonious action as a whole.

The techniques relating to an exposure apparatus of the present invention are described, for example, in United States Patent Applications No. 255,927, No. 260,398, No. 299,305, United States Patents No. 4,497,015, No. 4,666,273, No. 5,194,893, No. 5,253,110, No. 5,333,035, No. 5,365,051, No. 5,379,091, or the like. The reference of United States Patent Application No. 255,927 teaches an illumination optical system (using a laser source) applied to a scan type exposure apparatus. The reference of United States Patent Application No. 260,398 teaches an illumination optical system (using a lamp source) applied to a scan type exposure apparatus. The reference of United States Patent Application No. 299,305 teaches an alignment optical system applied to a scan type exposure apparatus. The reference of United States Patent No. 4,497,015 teaches an illumination optical system (using a lamp source) applied to a scan type exposure apparatus. The reference of United States Patent No. 4,666,273 teaches a step-and repeat type exposure apparatus capable of using the projection optical system of the present invention. The reference of United States Patent No. 5,194,893 teaches an illumination optical system, an illumination region, mask-side and reticle-side interferometers, a focusing optical system, alignment optical system, or the like. The reference of United States Patent No. 5,253,110 teaches an illumination optical system (using a laser source) applied to a step-and-repeat type exposure apparatus. The '110 reference can be applied to a scan type exposure apparatus. The reference of United States Patent No. 5,333,035 teaches an application of an illumination optical system applied to an exposure apparatus. The reference of United States Patent No. 5,365,051 teaches a auto-focusing system applied to an exposure apparatus. The reference of United States Patent No. 5,379,091 teaches an illumination optical system (using a laser source) applied to a scan type exposure apparatus.

Each embodiment according to the present invention will be described in detail.

Light supplied from the illumination optical system 1 illuminates the reticle R to form an image of the light source 100 at the pupil position of the projection optical system 5 (the position of aperture stop AS 6). Namely, the illumination optical system 1 uniformly illuminates the reticle R under Köhler illumination. Then the pattern image of reticle R illuminated under Köhler illumination is projected (or transferred) onto the wafer W.

The present embodiment shows an example of the projection optical system in which the light source disposed inside the illumination optical system 1 is a mercury lamp for supplying the i-line (365 nm). The structure of the projection optical system in each embodiment will be described by reference to Fig. 3 to Fig. 6. Fig. 3 to Fig. 6 are lens structural drawings of the projection optical systems in the first to fourth embodiments, respectively, according to the present invention.

As shown in Fig. 3 to Fig. 6, the projection optical system in each embodiment has a first lens group G_1 with a positive refracting power, a second lens group G_2 with a negative refracting power, a third lens group G_3 with a positive refracting power, a fourth lens group G_4 with a negative refracting power, and a fifth lens group G_5 with a positive refracting power in order from the side of reticle R as a first object, is arranged as substantially telecentric on the object side (reticle R side) and on the image side (wafer W side), and has a reduction magnification.

In the projection optical system in each of the embodiments shown in Fig. 3 to Fig. 6, an object-to-image distance (a distance along the optical axis from the object plane to the image plane, or a distance along the optical axis from the reticle R to wafer W) L is 1000, an image-side numerical aperture NA is 0.3, a projection magnification β is 1/2.5, and a diameter of an exposure area on the wafer W is 51.9.

First described is a specific lens arrangement of the first embodiment shown in Fig. 3. The first lens group G_1 has a positive lens (positive lens of a biconvex shape) L_{11} with a convex surface to the image, a negative lens of a biconcave shape L_{12}, a positive lens (positive lens of a biconvex shape) L_{13} with a convex surface to the object, and a positive lens of a biconvex shape L_{14} in order from the object side. The image means a pattern image which is projected onto the image plane P2 when exposure light from the illumination optical system 1 passes through the reticle R, and object means a pattern on the object plane P1 of the reticle R.

The second lens group G_2 has a negative lens (negative meniscus lens: front lens) L_{2F} disposed as closest to the object and shaped with a concave surface to the image, a negative meniscus lens (rear lens) L_{2R} disposed as closest to the image and shaped with a concave surface to the object, and an intermediate lens group G_{2M} with a negative refracting power disposed between these negative lens L_{2F} and negative lens L_{2R}. This intermediate lens group G_{2M} has a positive lens (positive lens of a biconvex shape: first lens) L_{M1} shaped with a convex surface to the object, a negative meniscus lens (second lens) L_{M2} shaped with a concave surface to the image, and a negative lens (negative lens of a biconcave shape: third lens) L_{M3} shaped with a concave surface to the image in order from the object side.

The third lens group G_3 has two positive lenses (positive meniscus lenses) L_{31}, L_{32} each shaped with a convex surface to the image, a positive lens (positive lens of a biconvex shape) L_{33} shaped with a convex surface to the image, a positive lens (positive lens of a biconvex shape) L_{34} shaped with a convex surface to the object, and two positive lenses (positive meniscus lenses) L_{35}, L_{36} each shaped with a convex surface to the object in order from the object side.

The fourth lens group G_4 has a negative lens (negative lens of a biconcave shape: front lens) L_{41} disposed as closest to the object and shaped with a concave surface to the image, a negative lens (negative meniscus lens: rear lens) L_{43} disposed as closest to the image and shaped with a concave surface to the object, and a negative lens L_{42} of a biconcave shape disposed between these front lens L_{41} and rear lens L_{43}.

The fifth lens group G_5 has two positive lenses (positive meniscus lenses) L_{50}, L_{51} each shaped with a convex surface to the image, a positive lens (positive lens of a biconvex shape) L_{52} shaped with a convex surface to the image, a positive lens (positive lens of a biconvex shape: first positive lens) L_{53} shaped with a convex surface to the image, a negative lens L_{54} of a biconcave shape, a positive lens (positive meniscus lens: second positive lens) L_{55} shaped with a convex surface to the object, a positive lens (positive lens of a biconvex shape) L_{56} shaped with a convex surface to the object, a positive lens (positive lens of a biconvex shape) L_{57} shaped with a convex surface to the image, a negative lens L_{58} of a biconcave shape, and a positive lens (positive meniscus lens) L_{59} shaped with a convex surface to the object.

In the present embodiment, an aperture stop AS is disposed between the image-side concave surface of the front lens L_{41} and the object-side concave surface of the rear lens L_{43} in the fourth lens group G_4.

In the first lens group G_1 in the present embodiment, the image-side convex surface of the positive biconvex lens L_{11} and the object-side concave surface of the negative biconcave lens L_{12} have nearly equal curvatures and are arranged as relatively close to each other. Further, in the first lens group G_1, the image-side concave surface of the negative biconcave lens L_{12} and the object-side convex surface of the positive biconvex lens L_{13} have nearly equal curvatures and are arranged as relatively close to each other. In the present embodiment, each set of these lens surfaces arranged as close to each other are corrected for higher-order distortion.

Since in the present embodiment the front lens L_{2F} in the second lens group G_2 is formed in a meniscus shape and shaped with a concave surface to the image, coma can be reduced. Since in the present embodiment the first lens L_{M1} with the positive refracting power in the intermediate lens group G_{2M} in the second lens group G_2 is formed in a biconvex shape and shaped with a convex surface to the image and another convex surface to the object, appearance of spherical aberration of pupil can be suppressed.

Since the fourth lens group G_4 in the present embodiment is so arranged that the negative lens (front lens) L_{41} shaped with the concave surface to the image is disposed on the object side of the aperture stop AS and the negative

lens (rear lens) L_{43} with the concave surface to the object is disposed on the image side of the aperture stop AS, appearance of asymmetric aberration, particularly coma, can be suppressed.

Since in the present embodiment the lens groups of from the third lens group G_3 to the fifth lens group G_5 have a nearly symmetric refractive-power arrangement with respect to the aperture stop AS located in the fourth lens group, appearance of asymmetric aberration, particularly coma and distortion, can be suppressed.

Since in the present embodiment the first positive lens L_{53} in the fifth lens group G_5 has the convex surface opposed to the negative lens L_{54} of the biconcave shape and the other lens surface on the opposite side to the negative lens L_{54} is also a convex surface, higher-order spherical aberration can be prevented from arising with an increase of numerical aperture. In the present embodiment, spherical aberration and astigmatism is corrected by arranging the positive lens L_{57} with the convex surface to the image, the negative lens of the biconcave shape L_{58}, and the positive lens L_{59} with the convex surface to the object near the image plane.

The lens arrangement of the second embodiment shown in Fig. 4 is similar to that of the first embodiment as shown in Fig. 3 and described above. The third lens group in the second embodiment is different from that in the first embodiment in that the third lens group G_3 is composed of three positive lenses (positive meniscus lenses) L_{31}, L_{32}, L_{33} each shaped with a convey surface to the image, a positive lens (positive lens of a biconvex shape) L_{34} shaped with a convex surface to the object, and two positive lenses (positive meniscus lenses) L_{35}, L_{36} each shaped with a convex surface to the object in order from the object side, but the function thereof is the same as that of the first embodiment as described above.

Also, the fourth lens group in the second embodiment is different from that of the first embodiment in that the fourth lens group G_4 has a negative lens (negative meniscus lens: front lens) L_{41} disposed as closest to the object and shaped with a concave surface to the image, a negative lens (negative meniscus lens: rear lens) L_{43} disposed as closest to the image and shaped with a concave surface to the object, and a negative lens L_{42} of a biconcave shape disposed between these front lens L_{41} and rear lens L_{43}, but the function thereof is the same.

Further, in the second embodiment, the fifth lens group G_5 is different from that in the first embodiment in that the fifth lens group G_5 is composed of two positive lenses (positive meniscus lenses) L_{50}, L_{51} each shaped with a convex surface to the image, a positive lens L_{52} of a biconvex shape, a positive lens (positive lens of a biconvex shape: first positive lens) L_{53} shaped with a convex surface to the image, a negative lens L_{54} of a biconvex shape, a positive lens (positive lens of a biconvex shape: second positive lens) L_{55} shaped with a convex surface to the object, a positive lens (positive lens of a biconvex shape) L_{56} shaped with a convex surface to the object, a positive lens (positive meniscus lens) L_{57} shaped with a convex surface to the image, a negative lens L_{58} of a biconcave shape, and a positive lens (positive meniscus lens) L_{59} shaped with a convex surface to the object in order from the object side.

Also in the present embodiment, the aperture stop AS is disposed between the image-side concave surface of the front lens L_{41} and the object-side concave surface of the rear lens L_{43} in the fourth lens group G_4.

Since the present embodiment is so arranged that the first positive lens L_{53} in the fifth lens group G_5 has the convex surface opposed to the negative biconcave lens L_{54} and the other lens surface on the opposite side to the negative lens L_{54} is also a convex surface and that the second positive lens L_{55} in the fifth lens group has the convex surface opposed to the negative biconcave lens L_{54} and the other lens surface on the opposite side to the negative lens L_{54} is also the convex surface, higher-order spherical aberration can be prevented from appearing with an increase of numerical aperture. Since the present embodiment is so arranged that the second positive lens L_{55} in the fifth lens group has the convex surface opposed to the negative biconcave lens L_{54} and the other lens surface on the opposite side to the negative lens L_{54} is also the convex surface, the higher-order spherical aberration can be prevented from appearing with an increase of numerical aperture. Further, spherical aberration and astigmatism is corrected in the present embodiment by arranging the positive lens L_{57} with the convex surface to the image, the negative lens L_{58} of the biconcave shape, and the positive lens L_{59} with the convex surface to the object near the image plane.

The first and second lens groups G_1, G_2 and the fourth lens group G_4 in the second embodiment achieve the same functions as those in the first embodiment as described above.

The lens arrangement of the third embodiment shown in Fig. 5 is similar to that of the first embodiment as shown in Fig. 3 and described previously. Here, the third lens group G_3 in the third embodiment is different from that of the first embodiment in that the third lens group G_3 is composed of two positive lenses (positive meniscus lenses) L_{31}, L_{32} each shaped with a convex surface to the image, a positive lens (positive lens of a biconvex shape) L_{33}, a positive lens (positive meniscus lens) L_{34} shaped with a convex surface to the object, and two positive lenses (positive meniscus lenses) L_{35}, L_{36} each shaped with a convex surface to the object in order from the object side.

In the third embodiment, the fourth lens group is also different from that of the first embodiment in that the fourth lens group G_4 has a negative lens (negative meniscus lens: front lens) L_{41} disposed as closest to the object and shaped with a concave surface to the image, a negative lens (negative meniscus lens: rear lens) L_{43} arranged as closest to the image and shaped with a concave surface to the object, and a negative lens L_{42} of a biconcave shape disposed between these front lens L_{41} and rear lens L_{43}.

The fifth lens group G_5 in the third embodiment has a positive meniscus lens L_{50} shaped with a convex surface to the image, two positive lenses (positive lenses of biconvex shape) L_{51}, L_{52} each shaped with a convex surface to the

image, a positive lens (positive lens of a biconvex shape: first positive lens) L_{53} shaped with a convex surface to the image, a negative lens L_{54} of a biconcave shape, a positive lens (positive meniscus lens: second positive tens) L_{55} shaped with a convex surface to the object, a positive lens (positive lens of a biconvex shape) L_{56} shaped with a convex surface to the object, a positive lens (positive meniscus lens) L_{57} shaped with a convex surface to the image, a negative lens L_{58} of a biconcave shape, and a positive lens (positive meniscus lens) L_{59} shaped with a convex surface to the object in order from the object side.

Also in the present embodiment, the aperture stop AS is disposed between the image-side concave surface of the front lens L_{41} and the object-side concave surface of the rear lens L_{43} in the fourth lens group G_4.

Since the present embodiment is so arranged that the first positive lens L_{53} in the fifth lens group G_5 has a convex surface opposed to the negative biconcave lens L_{54} and the other lens surface on the opposite side to the negative lens L_{54} is also a convex surface, the higher-order spherical aberration can be prevented from arising with an increase of numerical aperture. The first to fourth lens groups G_1 to G_4 in the present embodiment have the same functions as those in the first embodiment as described previously.

The lens arrangement of the fourth embodiment shown in Fig. 6 is similar to that of the first embodiment as shown in Fig. 3 and described previously. Here, the first lens group G_1 in the fourth embodiment is different from that in the first embodiment in that the first lens group G_1 is composed of a positive lens (positive meniscus lens) L_{11} shaped with a convex surface to the image, a negative lens (negative lens of a biconcave shape) L_{12} shaped with a concave surface to the object, a positive lens (positive lens of a biconvex shape) L_{13} shaped with a convex surface to the object, and a positive lens L_{14} of a biconvex shape in order from the object side.

Further, the fourth lens group in the fourth embodiment is different from that in the first embodiment in that the fourth lens group G_4 has a negative lens (negative meniscus lens: front lens) L_{41} disposed as closest to the object and shaped with a concave surface to the image, a negative lens (negative meniscus lens: rear lens) L_{43} disposed as closest to the image and shaped with a concave surface to the object, and a negative lens L_{42} of a biconcave shape disposed between these front lens L_{41} and rear lens L_{43}.

Also in the present embodiment, the aperture stop AS is disposed between the image-side concave surface of the front lens L_{41} and the object-side concave surface of the rear lens L_{43} in the fourth lens group G_4.

Here, the first lens group G_1 in the present embodiment is so arranged that the image-side convex surface of the positive meniscus lens L_{11} and the object-side concave surface of the negative biconcave lens L_{12} have nearly equal curvatures and are arranged as relatively close to each other and that the image-side concave surface of the negative biconcave lens L_{12} and the object-side convex surface of the positive biconvex lens L_{13} have nearly equal curvatures and are arranged as relatively close to each other. In the present embodiment, higher-order distortion is corrected in each set of the lens surfaces arranged as close to each other. Since in the present embodiment the first positive lens L_{53} in the fifth lens group G_5 is arranged to have a convex surface opposed to the negative biconcave lens L_{54} and the other lens surface on the opposite side to the negative lens L_{54} is also a convex surface, the higher-order spherical aberration can be prevented from appearing with an increase of numerical aperture. The second to fourth lens groups G_2-G_4 in the fourth embodiment achieve the same functions as in the first embodiment described previously.

Table 1 to Table 8 to follow list values of specifications and correspondent values to the conditions for the respective embodiments in the present invention.

In the tables, left-end numerals represent orders from the object side (reticle R side). For example, the lens surface of No. 1 represents an object-side surface of the lens L_{11}, the lens surface of No. 2 represents an image-side surface of the lens L_{11}, and further the lens surface of No. 3 represents an object-side surface of the lens L_{12}. And, in the tables, r radii of curvatures of lens surfaces, d separations between lens surfaces, n refractive indices of glass materials for exposure wavelength λ of 365 nm, d_0 the distance along the optical axis from the first object (reticle R) to the lens surface (first lens surface) closest to the object (reticle R) in the first lens group G_1, β the projection magnification of projection optical system, Bf the distance along the optical axis from the lens surface closest to the image (wafer W) in the fifth lens group G_5 to the image plane (wafer W plane), NA the numerical aperture on the image side (wafer W side), of projection optical system, and L the object-to-image distance from the object plane P1 (reticle R plane) to the image plane P2 (wafer W plane). Further, in the tables, f_1 represents the focal length of the first lens group G_1, and similarly f_2 is the focal length of the second lens group G_2, f_3 is the focal length of the third lens group G_3, f_4 is the focal length of the fourth lens group G_4, f_5 is the focal length of the fifth lens group G_5, f_{1-3} is the composite focal length of the first lens group G_1 to the third lens group G_3, f_{4-5} is the composite focal length of the fourth lens group G_4 and the fifth lens group G_5, I is the axial distance from the first object (reticle) to the first-object-side focal point F of the entire projection optical system (provided that the first-object-side focal point F of the entire projection optical system means an intersecting point of emergent light with the optical axis when parallel light in the paraxial region with respect to the optical axis of the projection optical system is made incident from the second object side of the projection optical system and the light in the paraxial region is emergent from the projection optical system), f_n is the composite focal length of the second and third lenses (L_{M2}, L_{M3}) in the intermediate lens group G_{2M} in the second lens group G_2, r_{5p1} is the radius of curvature of the lens surface on the image side (wafer W side), of the first positive lens (L_{53}) in the fifth lens group G_5, r_{5n1} is the radius of curvature of the lens surface on the object side (reticle R side), of the negative biconcave lens (L_{54}) in the fifth

lens group G_5, r_{5p2} is the radius of curvature of the lens surface on the object side (reticle R side), of the second positive lens (L_{55}) in the fifth lens group G_5, r_{5n2} is the radius of curvature of the lens surface on the image side (wafer W side), of the negative biconcave lens (L_{54}) in the fifth lens group G_5, r_{4F} is the radius of curvature of the lens surface on the image side (wafer W side), of the front lens (L_{41}) in the fourth lens group G_4, r_{4R1} is the radius of curvature of the lens surface on the object side (reticle R side), of the rear lens (L_{43}) in the fourth lens group G_4, r_{4R2} is the radius of curvature of the lens surface on the image side (wafer W side), of the rear lens (L_{43}) in the fourth lens group G_4, D is the axial distance from the lens surface on the image side (wafer W side), of the third lens (L_{M3}) in the intermediate lens group G_{2M} in the second lens group G_2 to the lens surface on the object side (reticle R side), of the rear lens (L_{2R}) in the second lens group G_2, Φ_{21} is the refracting power of the lens surface on the image side (wafer W side), of the first lens (L_{M1}) in the intermediate lens group G_{2M} in the second lens group G_2, f_{2F} is the focal length of the front lens (r_{2F}) in the second lens group G_2, f_{2R} is the focal length of the rear lens (r_{2R}) in the second lens group G_2, f_{22} is the focal length of the second lens (L_{M2}) in the intermediate lens group G_{2M} in the second lens group G_2, and f_{23} is the focal length of the third lens (L_{M3}) in the intermediate lens group G_{2M} in the second lens group G_2.

(Table 1) First Embodiment

d_0 = 68.278

β = 1/2.5

NA = 0.3

Bf = 23.366

L = 1000

	r	d	n
1	412.4222	29.607	1.53627
2	-194.9125	5.422	1.00000
3	-162.8459	12.500	1.66638
4	267.2084	2.921	1.00000
5	271.8309	34.952	1.53627
6	-213.4911	0.987	1.00000
7	266.2656	26.766	1.53627
8	-468.7409	4.375	1.00000
9	270.4805	18.099	1.53627
10	135.8598	16.655	1.00000
11	937.8750	16.667	1.53627
12	-4807.94	0.833	1.00000
13	234.5026	23.371	1.53627
14	111.3855	24.221	1.00000
15	-175.0000	12.500	1.53627
16	267.3503	62.757	1.00000
17	-194.6379	16.307	1.66638
18	-261.8110	16.666	1.00000
19	-169.1972	29.165	1.53627

20	-166.7514	0.833	1.00000
21	-3759.37	20.038	1.53627
22	-345.5933	0.833	1.00000
23	996.1417	26.307	1.53627
24	-276.4660	0.833	1.00000
25	191.6667	28.348	1.53627
26	-2773.83	0.833	1.00000
27	213.3310	18.065	1.53627
28	570.8902	0.833	1.00000
29	171.5888	18.299	1.53627
30	230.1838	17.084	1.00000
31	-1808.22	24.761	1.53627
32	85.0461	14.955	1.00000
33	-242.2847	12.500	1.66638
34	227.9011	24.251	1.00000
35	-117.1621	12.500	1.66638
36	-846.9536	12.500	1.00000
37	-264.5842	20.833	1.53627
38	-152.1755	13.063	1.00000
39	-2730.03	27.827	1.53627
40	-200.3783	1.246	1.00000
41	363.0091	23.528	1.53627
42	-409.7989	0.833	1.00000
43	191.3014	28.174	1.53627
44	-801.7430	7.180	1.00000
45	-346.4386	12.500	1.66638

46	218.5468	3.510	1.00000
47	229.2437	19.004	1.53627
48	1794.80	0.833	1.00000
49	203.1685	27.146	1.53627
50	-500.0000	83.333	1.00000
51	333.2970	12.500	1.53627
52	-1423.25	6.960	1.00000
53	-153.2454	12.500	1.53627
54	96.2920	0.833	1.00000
55	66.7883	18.011	1.53627
56	450.4200	(Bf)	1.00000

(Table 2)

Correspondent Values to the Conditions for First Embodiment	
(1)	f1/f3 = 1.93
(2)	f2/f4 = 1.94
(3)	f5/L = 0.104
(4)	f1-3/f4-5 = 2.01
(5)	l/L = 2.55
(6)	fn/L = -0.131
(7)	(r5p1 - r5n1)/(r5p1 + r5n1) = 0.397
(8)	(r5p2 - r5n2)/(r5p2 + r5n2) = 0.0239
(9)	f3/f5 = 0.990
(10)	|(r4F - r4R1)/(r4F + r4R1)| = 6.93
(11)	D/L = 0.0628
(12)	f4/L = -0.0493
(13)	f2/L = -0.953
(14)	(r4R1 - r4R2)/(r4R1 + r4R2) = -0.757
(15)	1/(ϕ21 • L) = 8.97
(16)	f2F/f2R = 0.424
(17)	f22/f23 = 2.17

(Table 3) Second Embodiment

d0 = 70.950

β = 1/2.5

NA = 0.3

Bf = 23.416

L = 1000

	r	d	n
1	438.9848	29.298	1.61536
2	-245.0390	8.217	1.00000
3	-166.0688	19.167	1.61298
4	376.2596	6.534	1.00000
5	785.8269	24.879	1.61536
6	-272.5224	0.833	1.00000
7	275.3049	30.833	1.61536
8	-347.8966	0.833	1.00000
9	257.3250	15.417	1.61536
10	123.5907	21.196	1.00000
11	571.2622	25.000	1.48734
12	-968.7476	0.833	1.00000
13	154.2173	14.583	1.61536
14	100.9802	27.566	1.00000
15	-188.6211	14.583	1.61536
16	265.1972	61.127	1.00000
17	-116.3706	15.417	1.61298
18	-265.4487	7.179	1.00000
19	-179.9332	24.447	1.48734

20	-149.1401	0.833	1.00000
21	-369.4268	17.894	1.61536
22	-192.0942	0.833	1.00000
23	-904.4969	19.479	1.48734
24	-242.2845	0.833	1.00000
25	226.8559	26.591	1.61536
26	-1048.27	0.833	1.00000
27	216.9626	21.096	1.61536
28	766.4880	0.833	1.00000
29	165.7666	20.473	1.61536
30	383.2054	5.876	1.00000
31	956.6166	27.675	1.61536
32	87.2387	18.200	1.00000
33	-201.4157	12.500	1.61298
34	213.6915	36.474	1.00000
35	-138.4657	12.500	1.61298
36	-2357.25	8.609	1.00000
37	-241.5240	17.723	1.61536
38	-204.8462	1.448	1.00000
39	-1852.25	22.824	1.61536
40	-174.0053	0.833	1.00000
41	268.5612	28.273	1.48734
42	-355.5957	0.833	1.00000
43	332.4732	22.101	1.61536
44	-701.8630	9.127	1.00000
45	-273.7240	18.333	1.61298

46	155.0581	3.328	1.00000
47	161.9132	29.479	1.61536
48	-1617.27	0.833	1.00000
49	188.0944	29.979	1.48734
50	-532.8834	87.293	1.00000
51	-1061.89	17.900	1.61536
52	-186.0014	4.601	1.00000
53	-126.4247	12.500	1.61536
54	102.5376	0.833	1.00000
55	73.4643	17.917	1.61536
56	1587.70	(Bf)	1.00000

(Table 4)

Correspondent Values to the Conditions for Second Embodiment	
(1)	f1/f3 = 2.04
(2)	f2/f4 = 1.40
(3)	f5/L = 0.110
(4)	f1-3/f4-5 = 2.00
(5)	I/L = 2.84
(6)	fn/L = -0.130
(7)	(r5p1 - r5n1)/(r5p1 + r5n1) = 0.439
(8)	(r5p2 - r5n2)/(r5p2 + r5n2) = 0.0216
(9)	f3/f5 = 0.824
(10)	|(r4F - r4R1)/(r4F + r4R1)| = 4.41
(11)	D/L = 0.0611
(12)	f4/L = -0.0502
(13)	f2/L = -0.0701
(14)	(r4R1 - r4R2)/(r4R1 + r4R2) = -0.889
(15)	1/(ϕ21 • L) = 1.99
(16)	f2F/f2R = 1.15
(17)	f22/f23 = 3.00

(Table 5) Third Embodiment

d0 = 68.124

β = 1/2.5

NA = 0.3

Bf = 23.366

L = 1000

	r	d	n
1	576.4927	26.973	1.53627
2	-237.2020	7.177	1.00000
3	-170.9914	12.500	1.66638
4	444.8712	7.568	1.00000
5	1792.61	28.021	1.53627
6	-212.4851	0.417	1.00000
7	314.5147	32.434	1.53627
8	-315.7722	0.417	1.00000
9	233.5823	16.667	1.53627
10	190.6719	9.323	1.00000
11	398.7885	19.814	1.53627
12	-850.0000	0.417	1.00000
13	157.1780	15.523	1.53627
14	91.0735	24.101	1.00000
15	-462.5909	12.500	1.53627
16	149.0328	53.333	1.00000
17	-109.6238	16.864	1.66638
18	-816.8008	31.244	1.00000
19	-209.8917	39.167	1.53627

20	-170.3243	7.090	1.00000
21	-872.0596	29.168	1.53627
22	-196.3948	0.417	1.00000
23	653.4305	33.251	1.53627
24	-297.0283	0.417	1.00000
25	180.9216	29.535	1.53627
26	954.6750	0.417	1.00000
27	175.7978	20.187	1.53627
28	318.5177	0.894	1.00000
29	170.1111	21.193	1.53627
30	238.3822	12.372	1.00000
31	685.7469	24.414	1.53627
32	79.6257	16.619	1.00000
33	-253.6105	12.500	1.66638
34	147.9984	34.820	1.00000
35	-202.3445	12.925	1.66638
36	-435.0316	29.554	1.00000
37	-248.2723	18.070	1.53627
38	-209.1025	1.743	1.00000
39	631.5679	22.445	1.53627
40	-270.4465	0.417	1.00000
41	195.1878	27.668	1.53627
42	-704.7159	0.417	1.00000
43	173.6696	29.574	1.53627
44	-487.8900	5.254	1.00000
45	-356.1380	12.500	1.66638

45	128.7500	5.466	1.00000
47	150.0000	21.894	1.53627
48	1460.88	0.417	1.00000
49	216.4808	26.203	1.53627
50	-849.2433	19.707	1.00000
51	-323.6034	26.786	1.53627
52	-192.9683	16.980	1.00000
53	-139.3306	12.500	1.53627
54	124.1610	1.434	1.00000
55	72.8408	18.816	1.53627
56	752.1024	(Bf)	1.00000

(Table 6)

Correspondent Values to the Conditions for Third Embodiment	
(1)	f1/f3 = 2.48
(2)	f2/f4 = 1.45
(3)	f5/L = 0.112
(4)	f1-3/f4-5 = 1.97
(5)	l/L = 2.42
(6)	fn/L = -0.138
(7)	(r5p1 - r5n1)/(r5p1 + r5n1) = 0.156
(8)	(r5p2 - r5n2)/(r5p2 + r5n2) = 0.0762
(9)	f3/f5 = 0.859
(10)	|(r4F - r4R1)/(r4F + r4R1)| = 2.30
(11)	D/L = 0.0533
(12)	f4/L = -0.0604
(13)	f2/L = -0.0873
(14)	(r4R1 - r4R2)/(r4R1 + r4R2) = -0.365
(15)	1/(φ21 • L) = 1.59
(16)	f2F/f2R = 11.7
(17)	f22/f23 = 2.11

(Table 7) Fourth Embodiment

d0 = 66.958

β ≒ 1/2.5

NA = 0.3

Bf = 24.679

L = 1000

	r	d	n
1	-590.3602	17.187	1.61536
2	-247.2986	11.149	1.00000
3	-141.4186	12.500	1.61298
4	592.7528	8.779	1.00000
5	1693.50	35.323	1.61536
6	-181.2212	1.297	1.00000
7	359.6900	31.975	1.61536
8	-436.8156	0.417	1.00000
9	272.6790	16.667	1.61536
10	203.2115	5.189	1.00000
11	249.7060	27.859	1.48734
12	-833.3333	0.417	1.00000
13	150.8961	26.445	1.61536
14	92.9760	25.814	1.00000
15	-494.8144	12.500	1.61536
16	154.4961	52.083	1.00000
17	-109.5902	18.030	1.61298
18	-4166.67	18.750	1.00000
19	-558.4031	33.333	1.48734

20	-153.2906	16.830	1.00000
21	-510.6857	19.362	1.61536
22	-249.6976	0.417	1.00000
23	2759.07	33.333	1.48734
24	-204.7557	0.417	1.00000
25	198.3871	25.098	1.61536
26	765.2665	0.417	1.00000
27	186.3753	19.881	1.61536
28	369.6797	1.171	1.00000
29	172.2863	20.796	1.61536
30	239.5223	12.690	1.00000
31	470.2886	23.902	1.61536
32	82.5312	16.699	1.00000
33	-210.5282	29.277	1.61298
34	173.4522	25.554	1.00000
35	-161.8557	12.500	1.61298
36	-966.7899	27.185	1.00000
37	-564.2941	16.575	1.61536
38	-188.0721	0.417	1.00000
39	542.4653	13.931	1.61536
40	-18771.98	0.417	1.00000
41	227.1766	29.254	1.48734
42	-237.4964	0.417	1.00000
43	217.3657	22.437	1.61536
44	-992.8784	7.486	1.00000
45	-257.7989	12.500	1.61298

46	117.9183	1.851	1.00000
47	120.6975	25.724	1.61536
48	1294.79	0.417	1.00000
49	193.0318	32.321	1.48734
50	-587.1447	28.790	1.00000
51	-811.6837	20.343	1.61536
52	-240.9737	22.422	1.00000
53	-125.4616	12.500	1.61536
54	152.5752	0.417	1.00000
55	76.9324	18.904	1.61536
56	2095.86	(Bf)	1.00000

(Table 8)

Correspondent Values to the Conditions for Fourth Embodiment	
(1)	f1/f3 = 2.75
(2)	f2/f4 = 1.73
(3)	f5/L = 0.107
(4)	f1-3/f4-5 = 2.06
(5)	l/L = 2.41
(6)	fn/L = -0.135
(7)	(r5p1 - r5n1)/(r5p1 + r5n1) = 0.587
(8)	(r5p2 - r5n2)/(r5p2 + r5n2) = 0.0116
(9)	f3/f5 = 0.900
(10)	$\vert$(r4F - r4R1)/(r4F + r4R1)$\vert$ = 3.08
(11)	D/L = 0.0521
(12)	f4/L = -0.0541
(13)	f2/L = -0.0939
(14)	(r4R1 - r4R2)/(r4R1 + r4R2) = -0.713
(15)	1/(ϕ21 • L) = 1.71
(16)	f2F/f2R = 7.76
(17)	f22/f23 = 2.51

It is understood from the above values of specifications for the respective embodiments that the projection optical systems according to the embodiments achieved satisfactory telecentricity on the object side (reticle R side) and an the image side (wafer W side) as securing the wide exposure areas and relatively large numerical apertures.

Fig. 7 to Fig. 10 are aberration diagrams to show aberrations in the first to fourth embodiments.

Here, in each aberration diagram, NA represents the numerical aperture of the projection optical system, and Y the image height, and in each astigmatism diagram, the dashed line represents the meridional image surface and the solid line the sagittal image surface.

It is understood from comparison of the aberration diagrams that the aberrations are corrected in a good balance in each embodiment even with a wide exposure area (image height) and a relatively large numerical aperture, particularly, distortion is extremely well corrected up to nearly zero throughout the entire image, thus achieving the projection optical system with high resolving power in a very wide exposure area.

The above-described embodiments showed the examples using the mercury lamp as a light source for supplying the exposure light of the i-line (365 nm), but it is needless to mention that the invention is not limited to the examples; for example, the invention may employ light sources including a mercury lamp supplying the exposure light of the g-line (435 nm), and extreme ultraviolet light sources such as excimer lasers supplying light of 193 nm or 248 nm.

In the above each embodiment the lenses constituting the projection optical system are not cemented to each other, which can avoid a problem of a change of cemented surfaces with time. Although in the above each embodiment the lenses constituting the projection optical system are made of a plurality of optic materials, they may be made of a single glass material, for example quartz (SiO_2) if the wavelength region of the light source is not a wide band.

As described above, the present invention can realize high-performance projection optical systems having relatively large numerical apertures and achieving the bitelecentricity and superior correction of aberrations in a very wide exposure area.

Particularly, the present invention can achieve high-performance projection optical systems well corrected for distortion throughout a very wide exposure area.

From the invention thus described, it will be obvious that the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

The basic Japanese Application No. 055979/1995 filed on March 15, 1995 is hereby incorporated by reference.

Claims

1. A projection optical system located between a first and second objects, for projecting an image of the first object onto the second object said projection optical system comprising a first lens group with a positive refracting power, a second lens group with a negative refracting power, a third lens group with a positive refracting power, a fourth lens group with a negative refracting power, and a fifth lens group with a positive refracting power in order from the side of said first object,

   wherein when f_1 is a focal length of said first lens group, f_2 is a focal length of said second lens group, f_3 is a focal length of said third lens group, f_4 is a focal length of said fourth lens group, f_5 is a focal length of said fifth lens group, $f_{1\text{-}3}$ is a composite focal length of said first lens group to third lens group, $f_{4\text{-}5}$ is a composite focal length of said fourth lens group and said fifth lens group, and L is a distance from said first object to said second object, the following conditions are satisfied:

$$0.1 < f_1/f_3 < 17$$

$$0.1 < f_2/f_4 < 14$$

$$0.01 < f_5/L < 0.8$$

$$f_{1\text{-}3}/f_{4\text{-}5} < 2.5.$$

2. A projection optical system according to claim 1, wherein a magnification of said projection optical system is 1/2.5.

3. A projection optical system according to claim 1, wherein when I is an axial distance from said first object to the first-object-side focal point of said entire projection optical system and L is the distance from said first object to said second object, the following condition is satisfied:

$$1.0 < I/L$$

4. A projection optical system according to claim 1, wherein said second lens group comprises a front lens with a negative refracting power disposed as closest to the first object and shaped with a concave surface to the second object, a rear lens of a meniscus shape with a negative refracting power disposed as closest to the second object and shaped with a concave surface to said first object, and an intermediate lens group disposed between the front lens in said second lens group and the rear lens in said second lens group,

wherein said intermediate lens group comprises at least a first lens with a positive refracting power, a second lens with a negative refracting power, and a third lens with a negative refracting power in order from the side of said first object, and

wherein when f_n is a composite focal length of from said second lens to said third lens in said second lens group and L is the distance from said first object to said second object, the following condition is satisfied:

$$-1.4 < f_n/L < -0.123.$$

5. A projection optical system according to claim 1, wherein said fifth lens group comprises a negative lens of a biconcave shape, a first positive lens disposed as adjacent to said negative lens of the biconcave shape on the first object side and shaped with a convex surface to the second object, and a second positive lens disposed as adjacent to said negative lens of the biconcave shape on the second object side and shaped with a convex surface to the first object.

6. A projection optical system according to claim 5, wherein when r_{5p1} is a radius of curvature of said convex surface of said first positive lens in said fifth lens group and r_{5n1} is a radius of curvature of a concave surface on the first object side, of said negative lens of the biconcave shape in said fifth lens group, the following condition is satisfied:

$$0 < (r_{5p1} - r_{5n1})/(r_{5p1} + r_{5n1}) < 1.$$

7. A projection optical system according to claim 5, wherein when r_{5n2} is a radius of curvature of a concave surface on the second object side, of said negative lens of the biconcave shape in said fifth lens group and r_{5p2} is a radius of curvature of said convex surface of the second positive lens in said fifth lens group, the following condition is satisfied:

$$0 < (r_{5p2} - r_{5n2})/(r_{5p2} + r_{5n2}) < 1.$$

8. A projection optical system according to claim 5, wherein said negative lens of the biconcave shape, said first positive lens, and said second positive lens are disposed between at least one positive lens in said fifth lens group and at least one positive lens in said fifth lens group.

9. A projection optical system according to claim 1, wherein when f_3 is the focal length of said third lens group and f_5 is the focal length of said fifth lens group, the following condition is satisfied:

$$0.80 < f_3/f_5 < 1.00.$$

10. A projection optical system according to claim 1, wherein said fourth lens group comprises a front lens with a negative refracting power disposed as closest to the first object and shaped with a concave surface to the second object, a rear lens with a negative refracting power disposed closest to the second object and shaped with a concave surface to the first object, and at least one negative lens disposed between the front lens in said fourth lens group and the rear lens in said fourth lens group, and wherein when r_{4F} is a radius of curvature of a surface on the second object side, of the front lens disposed as closest to the first object in said fourth lens group and r_{4R1} is a radius of curvature of a surface on the first object side of the rear lens disposed as closest to the second object in said fourth lens group, the following condition is satisfied:

$$1.03 < |(r_{4F} - r_{4R1})/(r_{4F} + r_{4R1})|.$$

11. A projection optical system according to claim 4, wherein when D is an axial distance from a second-object-side lens surface of the third lens with the negative refracting power in the intermediate lens group in said second lens group to a first-object-side lens surface of the rear lens in the second lens group and L is the distance from said first object to said second object, the following condition is satisfied:

$$0.05 < D/L < 0.4.$$

12. A projection optical system according to claim 1, wherein when f_4 is the focal length of said fourth lens group and L is the distance from said first object to said second object, the following condition is satisfied:

$$-0.098 < f_4/L < -0.005.$$

13. A projection optical system according to claim 1, wherein when f_2 is the focal length of said second lens group and L is the distance from said first object to said second object, the following condition is satisfied:

$$-0.8 < f_2/L < -0.050.$$

14. A projection optical system according to claim 1, wherein said fourth lens group comprises a front lens with a negative refracting power disposed as closest to the first object and shaped with a concave surface to the second object, a rear lens with a negative refracting power disposed as closest to the second object and shaped with a concave surface to the first object, and at least one negative lens disposed between said front lens in said fourth lens group and said rear lens in said fourth lens group, and wherein when r_{4R1} is a radius of curvature of a first-object-side surface of the rear lens disposed as closest to the second object in said fourth lens group and r_{4R2} is a radius of curvature of a second-object-side surface of said rear lens, the following condition is satisfied:

$$-1.00 \leqq (r_{4R1} - r_{4R2})/(r_{4R1} + r_{4R2}) < 0.$$

15. A projection optical system according to claim 4, wherein the first lens with the positive refracting power in the intermediate lens group in said second lens group has a lens shape with a convex surface to the second object, and

wherein when Φ_{21} is a refracting power of the second-object-side lens surface of the first lens with the positive refracting power in the intermediate lens group in said second lens group and L is the distance from said first object to said second object, the following condition is satisfied:

$$0.54 < 1/(\Phi_{21} \cdot L) < 10.$$

16. A projection optical system according to claim 4, wherein when f_{2F} is a focal length of the front lens with the negative refracting power disposed as closest to the first object in the second lens group and shaped with the concave surface to said second object and f_{2R} is a focal length of the rear lens with the negative refracting power disposed as closest to the second object in said second lens group and shaped with the concave surface to said first object, the following condition is satisfied:

$$0 \leqq f_{2F}/f_{2R} < 18.$$

17. A projection optical system according to claim 4, wherein the intermediate lens group in said second lens group has a negative refracting power.

18. A projection optical system according to claim 4, wherein among the lenses in said intermediate lens group only said second lens and said third lens have respective, negative refracting powers and wherein when f_{22} is a focal length of the second lens with the negative refracting power in said second lens group and f_{23} is a focal length of the third lens with the negative refracting power in said second lens group, the following condition is satisfied:

$$0.7 < f_{22}/f_{23}.$$

19. A projection optical system according to claim 1, wherein said first lens group comprises at least two positive lenses, said second lens group comprises at least two negative lenses, said third lens group comprises at least three positive lenses, said fourth lens group comprises at least three negative lenses, and said fifth lens group comprises at least five positive lenses and at least one negative lens.

20. An exposure apparatus comprising:

a first stage allowing a photosensitive substrate to be held on a main surface thereof;
an illumination optical system for emitting exposure light of a predetermined wavelength and transferring a predetermined pattern on a mask onto the substrate; and
a projection optical system provided between said first stage and said illumination, for projecting an image on the mask, on the substrate surface, said projection optical system having a first lens group with a positive refracting power, a second lens group with a negative refracting power, a third lens group with a positive refract-

ing power, a fourth lens group with a negative refracting power, and a fifth lens group with a positive refracting power in order from the side of said first object,

wherein when f_1 is a focal length of said first lens group, f_2 is a focal length of said second lens group, f_3 is a focal length of said third lens group, f_4 is a focal length of said fourth lens group, f_5 is a focal length of said fifth lens group, f_{1-3} is a composite focal length of said first lens group to third lens group, f_{4-5} is a composite focal length of said fourth lens group and said fifth lens group, and L is a distance from said first object to said second object, the following conditions are satisfied:

$$0.1 < f_1/f_3 < 17$$

$$0.1 < f_2/f_4 < 14$$

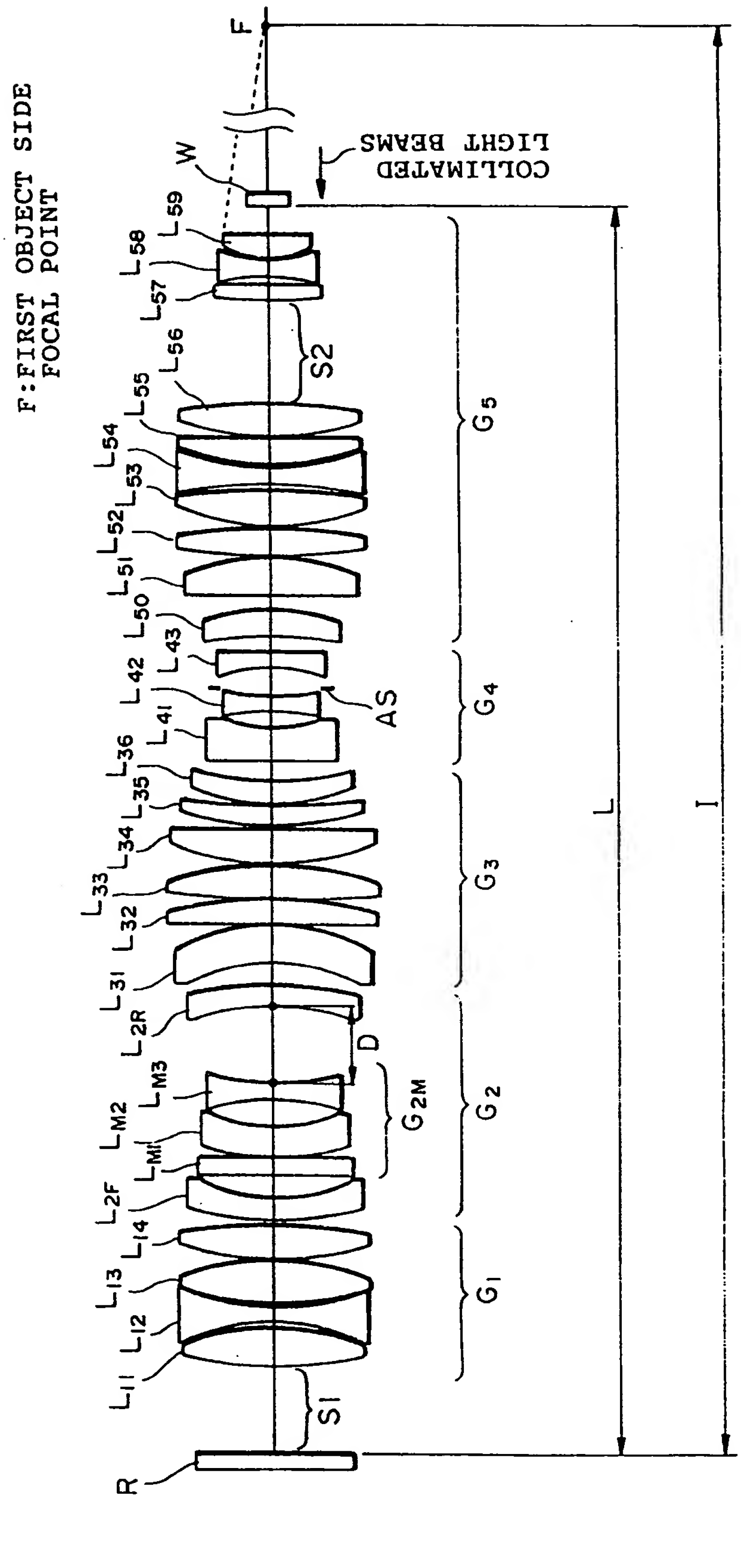
$$0.01 < f_5/L < 0.8$$

$$f_{1-3}/f_{4-5} < 2.5.$$

21. An exposure apparatus according to claim 20, wherein a magnification of said projection optical system is 1/2.5.

22. An exposure apparatus according to claim 20, further comprising a second stage for supporting the mask, and wherein said projection optical system is positioned between said first stage and said second stage.

Fig. 1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L57
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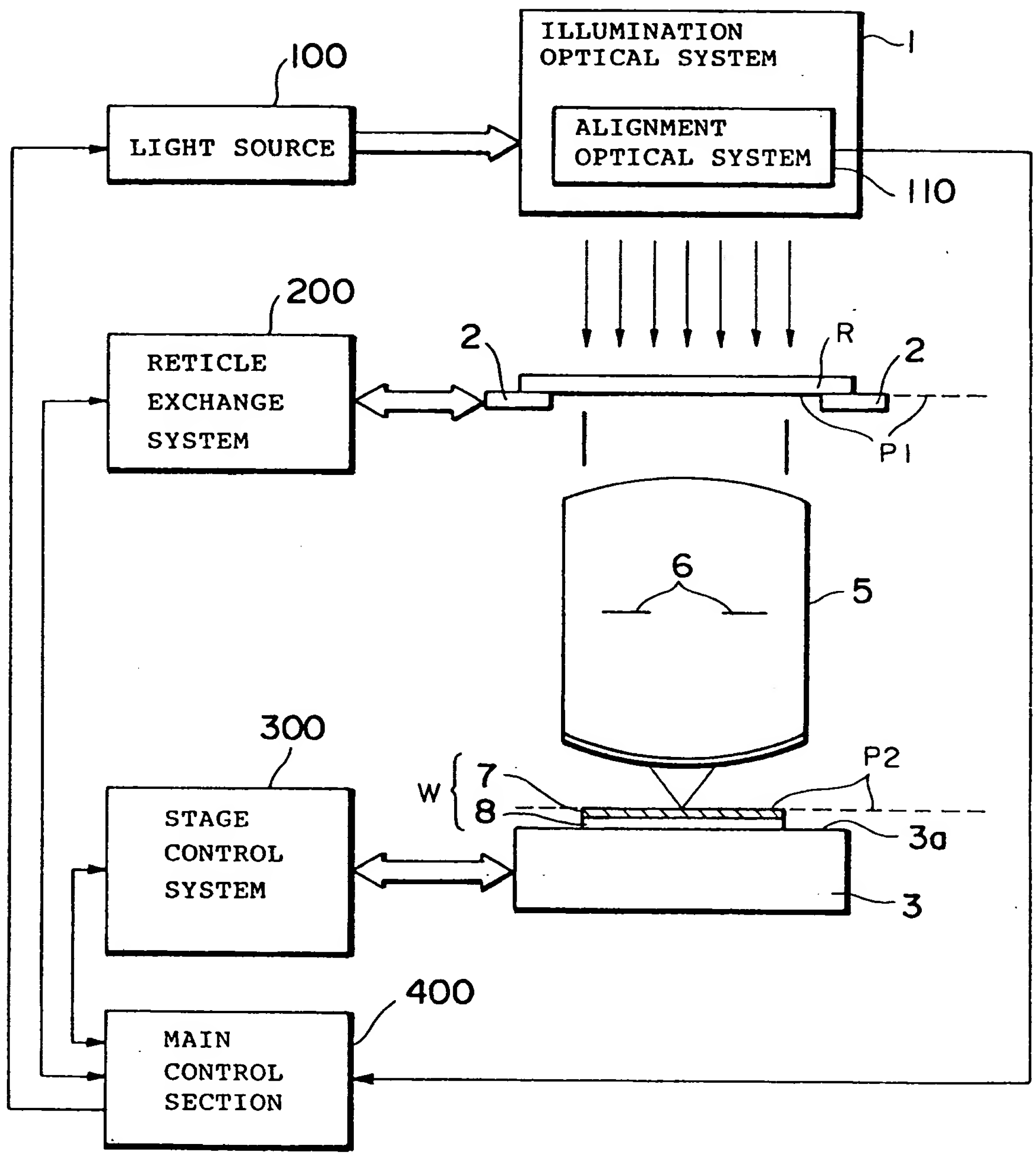
L55
L54
L53
L52
L51
L50
L43
L42
L41
AS
L36
L35
L34
L33
L32
L31
L2R
D
LM3
LM2
LM1
L2F
L14
L13
L12
L11
R
S1
S2
G1
G2
G2M
G3
G4
G5
L
I

Fig.2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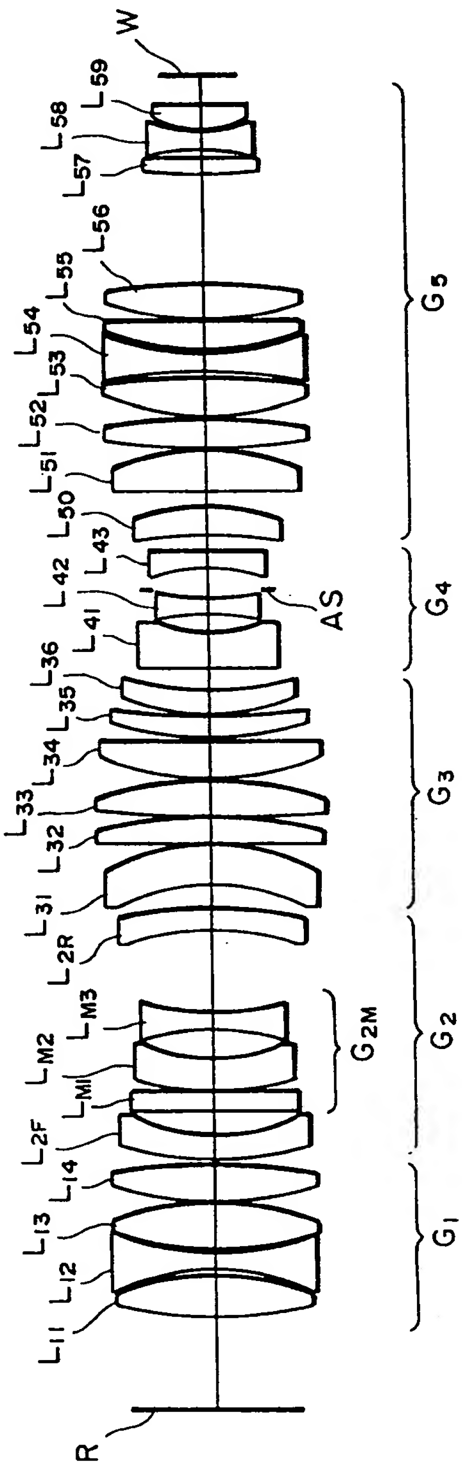
LIGHT SOURCE
ALIGNMENT OPTICAL SYSTEM
110
200
RETICLE EXCHANGE SYSTEM
2
R
2
P1
6
5
300
STAGE CONTROL SYSTEM
W
7
8
P2
3a
3
400
MAIN CONTROL SECTION

Fig. 3



W
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L58
L57
L56
L55
L54
L53
L52
L51
L50
L43
L42
L41
AS
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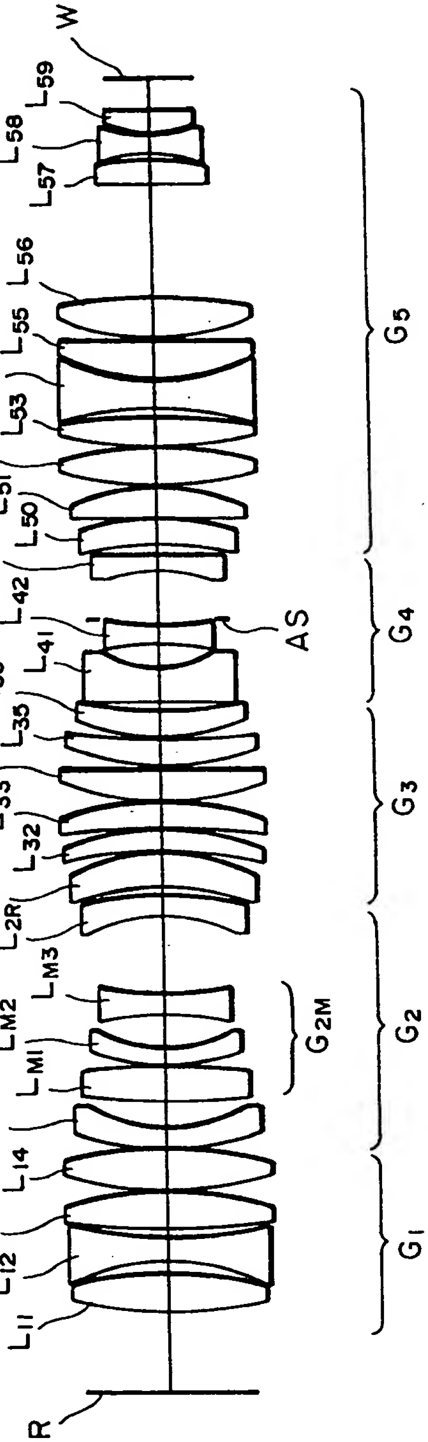
LM3
LM2
LM1
G2M
L2F
L14
L13
L12
L11
R
G5
G4
G3
G2
G1

Fig. 4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AS
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L_{35}
L_{34}
L_{33}
L_{32}
L_{31}
L_{2R}
L_{M3}
L_{M2}
L_{M1}
L_{2F}
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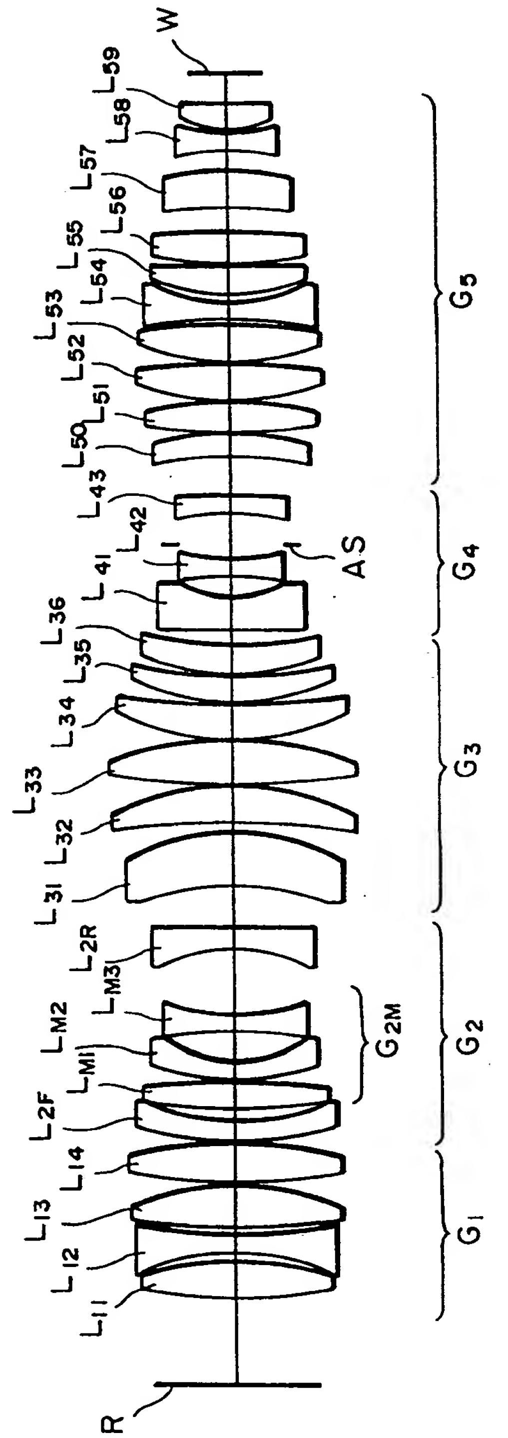
L_{11}
R
G_5
G_4
G_3
G_{2M}
G_2
G_1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L_{2R}
L_{M3}
L_{M2}
L_{M1}
L_{2F}
L_{14}
L_{13}
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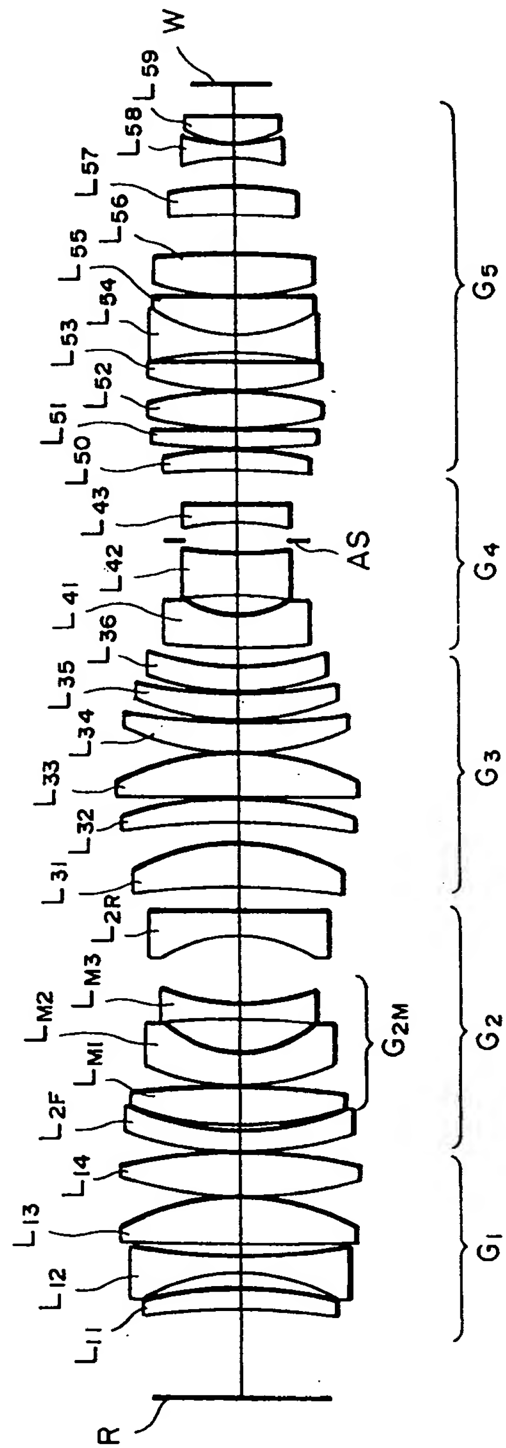
L_{11}
R
G_5
G_4
G_3
G_{2M}
G_2
G_1

Fig. 5

Fig. 6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L35
L34
L33
L32
L31
L2R
LM3
LM2
LM1
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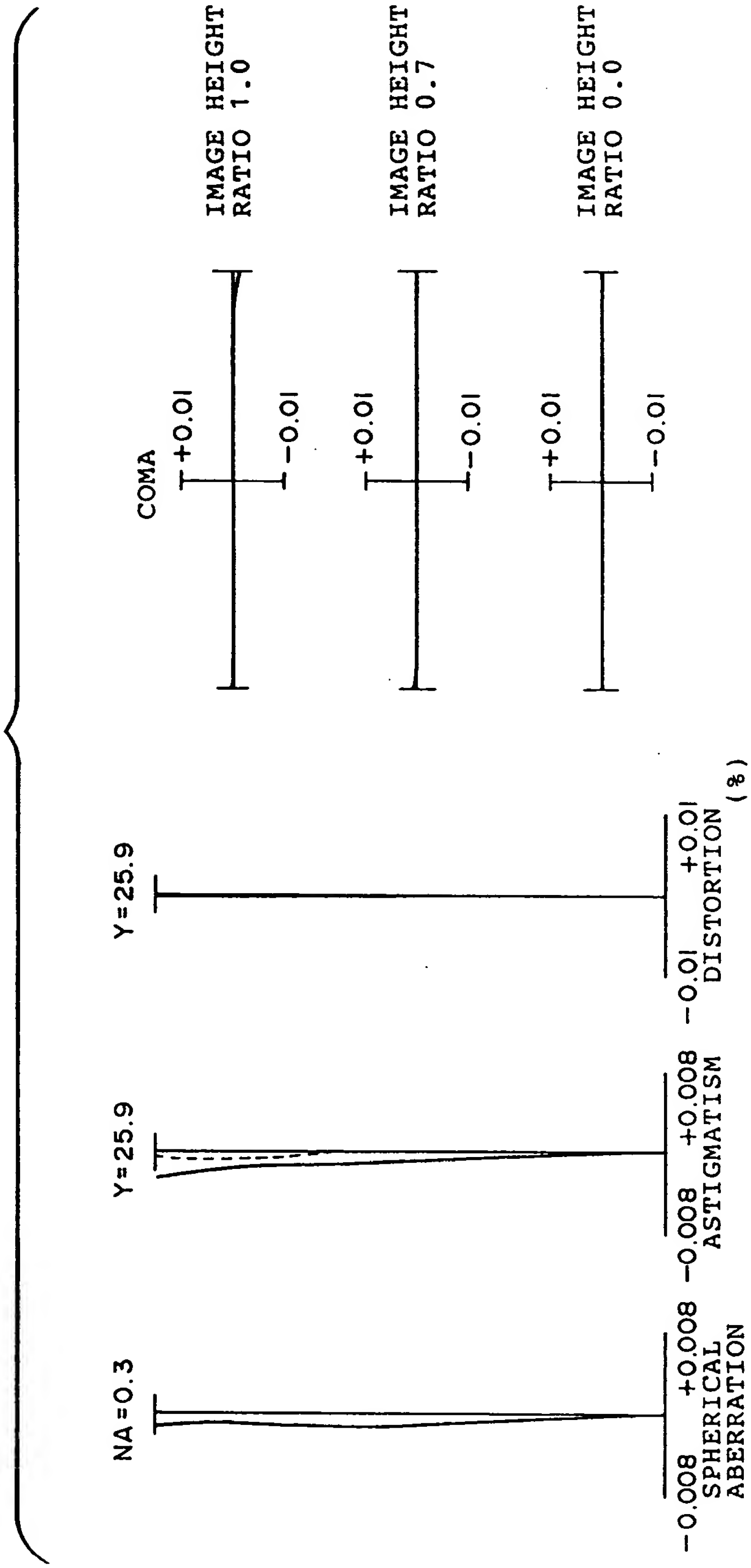
L13
L12
L11
R
G5
G4
G3
G2
G2M
G1

Fig. 7



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Y=25.9
Y=25.9
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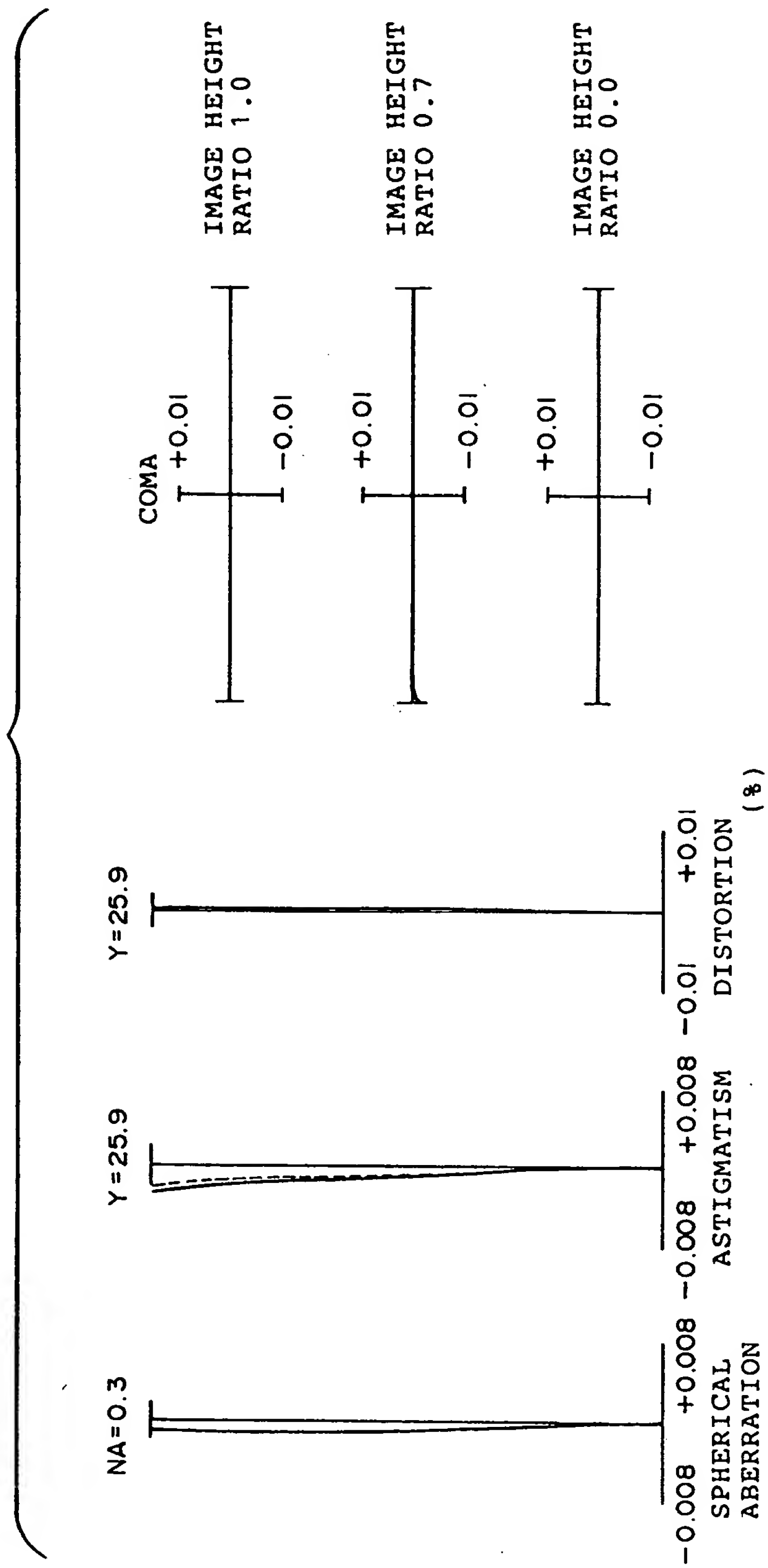
SPHERICAL ABERRATION
-0.008 +0.008
ASTIGMATISM
-0.01 +0.01
DISTORTION (%)
COMA
+0.01
-0.01
IMAGE HEIGHT RATIO 1.0
IMAGE HEIGHT RATIO 0.7
IMAGE HEIGHT RATIO 0.0

Fig. 8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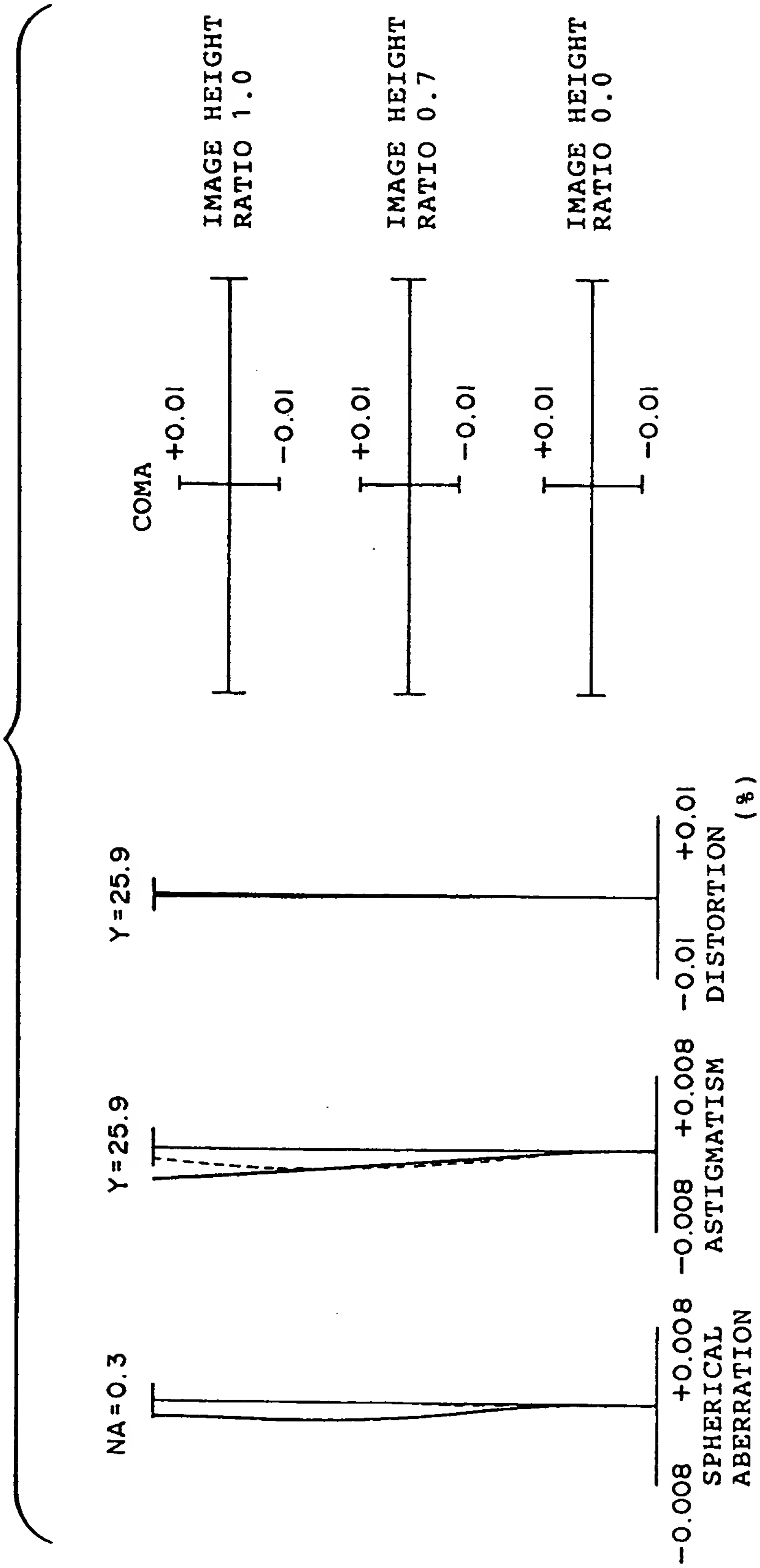
+0.008
SPHERICAL ABERRATION
Y=25.9
-0.008
+0.008
ASTIGMATISM
Y=25.9
-0.01
+0.01
DISTORTION
(%)
COMA
+0.01
-0.01
IMAGE HEIGHT RATIO 1.0
+0.01
-0.01
IMAGE HEIGHT RATIO 0.7
+0.01
-0.01
IMAGE HEIGHT RATIO 0.0

Fig. 9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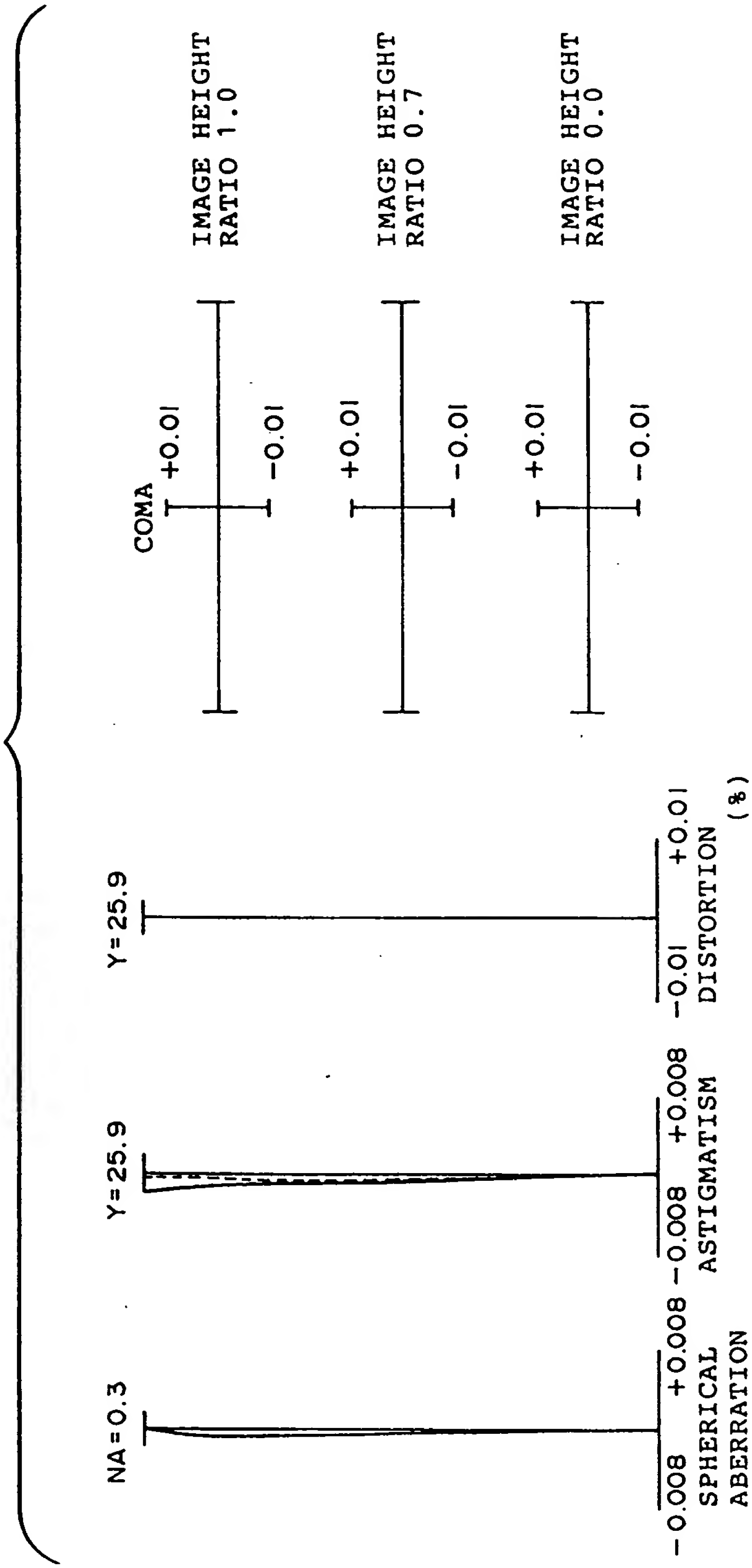
+0.008
SPHERICAL ABERRATION
Y=25.9
-0.008
+0.008
ASTIGMATISM
Y=25.9
-0.01
+0.01
DISTORTION
(%)
COMA
+0.01
-0.01
IMAGE HEIGHT RATIO 1.0
+0.01
-0.01
IMAGE HEIGHT RATIO 0.7
+0.01
-0.01
IMAGE HEIGHT RATIO 0.0

Fig. 10


COMA
+0.01
-0.01
IMAGE HEIGHT RATIO 1.0
IMAGE HEIGHT RATIO 0.7
IMAGE HEIGHT RATIO 0.0
NA=0.3
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+0.008
SPHERICAL ABERRATION
Y=25.9
ASTIGMATISM
-0.01
+0.01
DISTORTION
(%)